SECTION 3
Summary of Water Monitoring Data

This section summarizes water data collected between 2005 and 2007 from the ambient and outfall monitoring programs.

Data for individual stations and by parameter are provided in Appendix A. Station locator maps are provided in Section 2 along with specific information such as matrix, parameters, and frequency measured. Station coordinates are presented in Appendix F.

A summary of results for specific parameters (e.g., salinity, bacteria) are provided in this section. Also included in this section is a summary of climate data as precipitation and air temperature can affect water column results and fecal indicator bacteria levels.

3.1 2005-2007 Climate Data

Precipitation data measured at the Sea-Tac International Airport station (station #24233) were obtained from the National Climatic Data Center. Precipitation data measured at Vashon Island were obtained from the Vashon Island Treatment Plant on the eastern side of the island and Boeing Creek (station # 43U) data were obtained from the King County hydrologic data website at http://green.kingcounty.gov/WLR/Waterres/hydrology/GaugeTextSearch.aspx. Precipitation data at three separate sites located in King County are presented as rainfall patterns can vary dependent upon location. The three sites are representative of location-dependent rainfall patterns. Vashon Island, particularly the northern end, tends to receive higher amounts of precipitation than other areas within King County. The Boeing Creek station is located near the eastern Puget Sound shoreline, just south of Richmond Beach.

In terms of precipitation, 2005 was a typical year when compared to the 30-year average with a total annual rainfall of 35.44 inches at the Sea-Tac station. The total amount of rainfall in 2007 (38.95 inches) was also typical and just above the 30-year average. However, in 2006 there was a total of 48.42 inches of rain which was more than 15 inches above the 30-year average (Figure 3-1). The amount of rainfall that fell in 2006 was the second highest on record since 1969. In 2006, over 11 and 15 inches of rain fell in January and November, respectively. For 2005 and 2006, the total annual rainfall was 31.21 inches and 44.68 inches at the Boeing Creek respectively. The gage malfunctioned towards the end of 2007, therefore, the annual total is not available for this site. Between 2005 and 2007, the total annual rainfall at the Vashon Island TP station was 42.32 inches, 62.83 inches, and 45.48 inches, respectively. As stated above, Vashon Island receives more rainfall than other areas within King County and received, on average, more than 6.7 inches of rain than Sea-Tac in 2005 and 2007 and received over 14 inches more than Sea-Tac in 2006. Monthly rainfall totals for all three sites is provided in Figure 3-2.

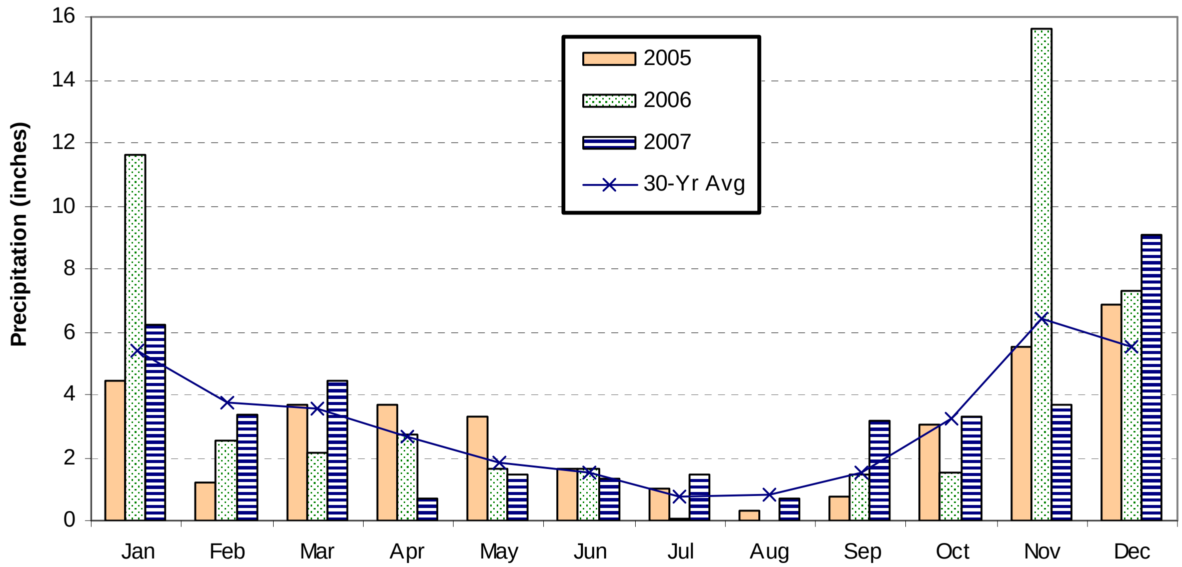


Figure 3-1. Total Monthly Precipitation at Sea-Tac Airport

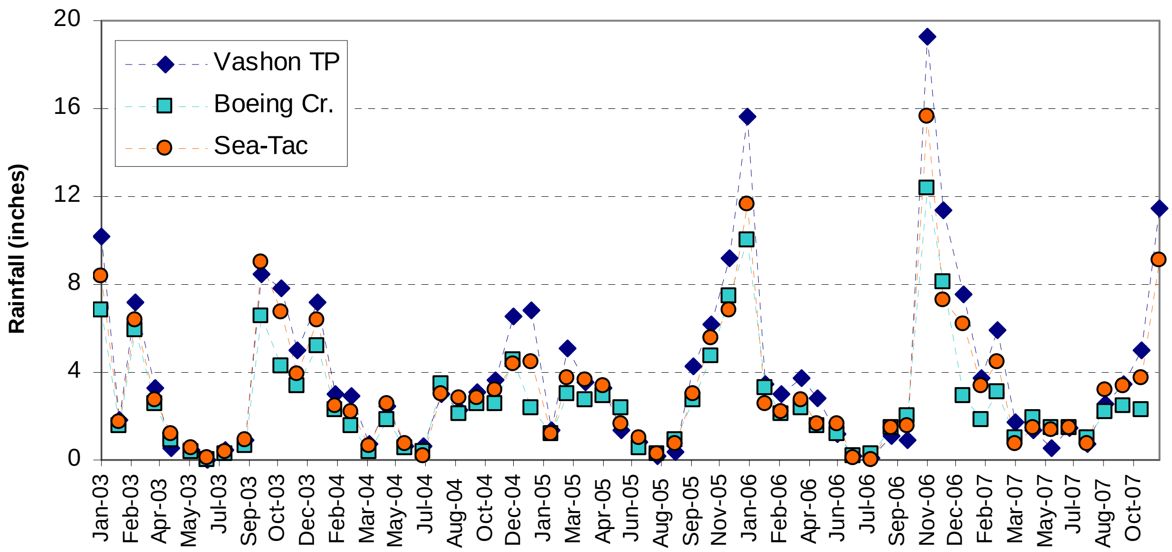


Figure 3-2. Monthly Precipitation at Three Locations in King County

Air temperature is also recorded at the Sea-Tac Airport. Average monthly air temperatures in 2005 were fairly typical when compared to the 30-year (yr) average, with slightly warmer spring temperatures. Although 2006 had a much warmer January and warmer May through September than the 30-yr average, February through April were slightly cooler than the 30-yr average as was October through December. Cooler air temperatures near the end of 2006 carried over into January 2007. The middle of 2007 was typical when compared to the 30-yr average, with cooler temperatures from June through the end of the year.

Around September 2006, a mild El Niño event (a warming episode of Pacific Ocean waters) developed in the Pacific Ocean and dissipated in early 2007. Warmer air temperatures preceding this El Niño event were apparent in June and July 2006. Although there were no days in 2005 with air temperatures above 90 ^{o}F, there were five days in 2006 with temperatures above 90^{o}F, four of which occurred in July and one in June. One day in 2007 (July) had an air temperature above 90 ^{o}F. Figure 3-3 shows average daily air temperatures for July between 2005 and 2007 and Figure 3-4 shows the departure from normal air temperatures for June.

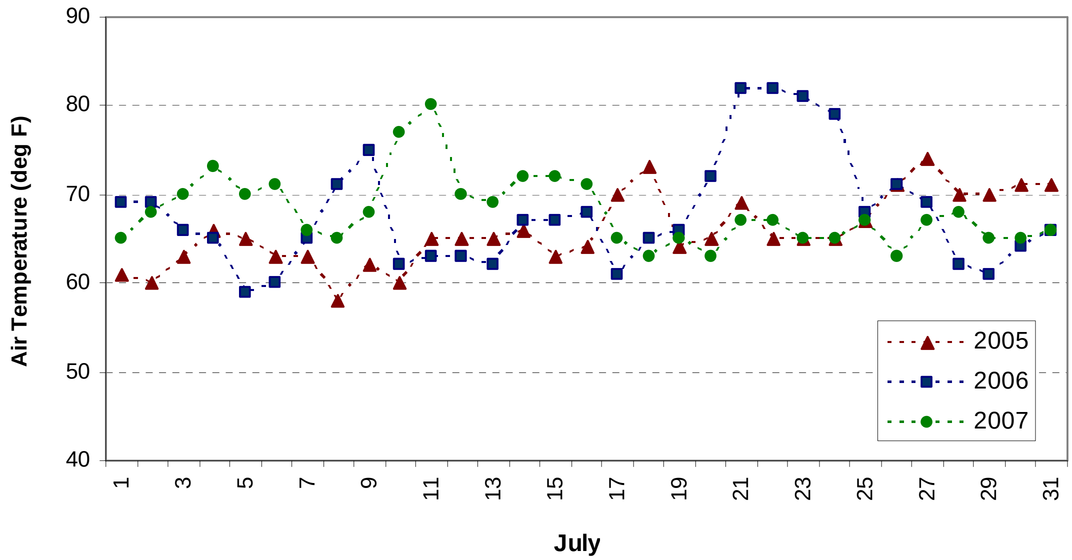


Figure 3-3. Average Daily Air Temperatures at Sea-Tac for July

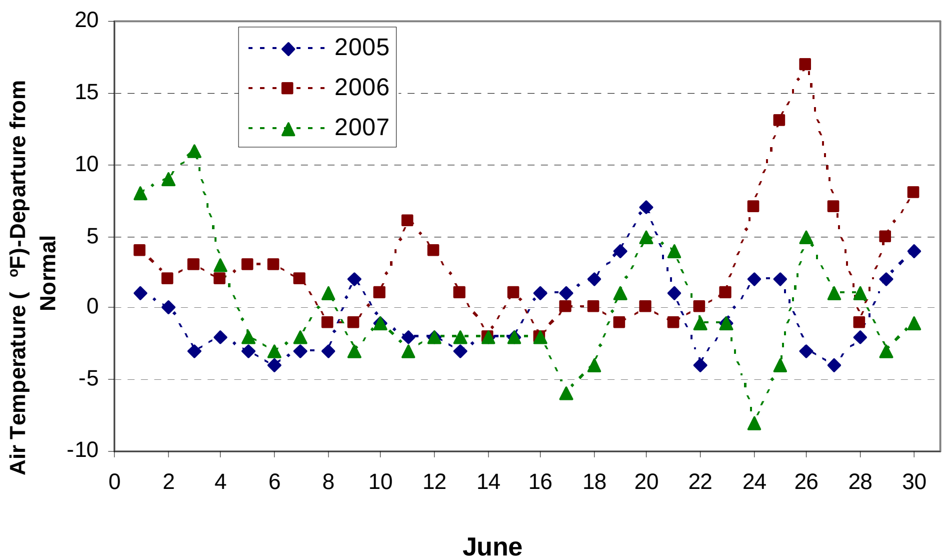


Figure 3-4. Departure from Normal Air Temperatures at Sea-Tac for June

3.2 Water Column Data Results

Water column sampling is a major component of the County's water quality monitoring program and includes offshore and beach sites (see sample locations in Section 2). The monitoring program is structured to detect natural seasonal changes in the water column and to identify anthropogenic inputs and influences.

Water quality parameters, including temperature, salinity, dissolved oxygen, total suspended solids, Secchi disk transparency, fluorescence (indicator of chlorophyll-*a*), pheophytin, photosynthetically active radiation, and nutrients (ammonia, nitrate+nitrite, and total phosphorus) were measured at all offshore stations in between 2005 and 2007 (see matrix tables in Section 2). Turbidity was measured at offshore stations in 2005 and transmissivity measured in 2006 and 2007 due to a method change. Temperature, salinity and nutrients were measured monthly at beach stations.

Fecal indicator bacteria (fecal coliforms and enterococci) were monitored monthly at all stations between 2005 and 2007.

3.2.1 Bacteria

Fecal coliforms and enterococci were monitored at all water stations. Washington State primary contact recreation fecal coliform standards for surface marine waters (formerly Class AA designation) state that organism counts shall not exceed a geometric mean value of 14 colonies/100 mL, and not more than 10 percent of the samples used to calculate the geometric mean may exceed 43 colonies/100 mL. Freshwater standards for primary contact recreation (formerly Class A designation) state that organism counts shall not exceed a geometric mean value of 100 colonies/100 mL, and not more than 10 percent of the samples used to calculate the geometric mean may exceed 200 colonies/100 mL. Freshwater standards for secondary contact recreation (formerly Class B designation) state that organism counts shall not exceed a geometric mean value of 200 colonies/100 mL, and not more than 10 percent of the samples used to calculate the geometric mean may exceed 400 colonies/100 mL. Marine fecal coliform standards are used in the evaluation of all stations except for the freshwater station located in Piper’s Creek, which is compared to the secondary contact freshwater fecal coliform standards.

Geometric mean values are calculated from the 12 most recent surface (1 meter) samples. Revisions to Ecology’s water quality standards recommend that the period of averaging not exceed 12 months. The monitoring program collects samples on a monthly basis, so the data are averaged over a 12-month period and geometric mean values should be interpreted accordingly.

Offshore Waters. As in previous years, all offshore outfall and ambient sites met both the geometric mean and peak standards for fecal coliforms between 2005 and 2007 (Tables 3-1 to 3-3). Most values for offshore waters were either 1 colony forming unit (CFU)/100 ml or not detected (Figure 3-5). Fecal coliform counts at the South TP and West Point TP outfalls were similar to the counts at the ambient stations.

Table 3-1. Summary of 2005 Offshore Station Compliance with Fecal Coliform Standards—Surface Waters at 1 M

Station	Meets Primary Contact Recreation Marine Surface Water Standards												
	Moving Geometric Mean [a] (≤14 CFU/100 mL)												Peak [b] (43 CFU/100 mL)
	J	F	M	A	M	J	J	A	S	O	N	D	
Outfall													
CK200P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSSK02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTBC43	--	--	--	--	--	--	--	--	--	--	--	Y	YES
LSEP01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSKQ06	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSJN02	--	--	--	--	--	--	--	--	--	--	--	Y	YES
Ambient													
JSUR01	--	--	--	--	--	--	--	--	--	--	--	Y	YES
KSBP01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTED04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSNT01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
NSEX01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES

[a]The geometric means were calculated using the 12 most recent fecal coliform values.

[b]The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

Table 3-2. Summary of 2006 Offshore Station Compliance with Fecal Coliform Standards—Surface Waters at 1 M

Station	Meets Primary Contact Recreation Marine Surface Water Standards												
	Moving Geometric Mean [a] (≤14 CFU/100 mL)												Peak [b] (43 CFU/100 mL)
	J	F	M	A	M	J	J	A	S	O	N	D	
Outfall													
CK200P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSSK02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTBC43	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
RT625NP	--	--	--	--	--	--	--	--	--	--	--	Y	YES
RT625SP	--	--	--	--	--	--	--	--	--	--	--	Y	YES
LSKQ06	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSJN02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
Ambient													
JSUR01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSBP01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTED04	--	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSNT01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSWH01	--	--	--	--	--	--	--	--	--	--	--	Y	YES
NSAJ02	--	--	--	--	--	--	--	--	--	--	--	Y	YES
NSEX01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES

[a]The geometric means were calculated using the 12 most recent fecal coliform values.

[b]The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

Table 3-3. Summary of 2007 Offshore Station Compliance with Fecal Coliform Standards—Surface Waters at 1 M

Station	Meets Primary Contact Recreation Marine Surface Water Standards: Moving Geometric Mean [a] (≤14 CFU/100 mL) J	F	M	A	M	J	J	A	S	O	N	D	Peak [b] (43 CFU/100 mL)
Outfall													
CK200P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSSK02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTBC43	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSEP01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSKQ06	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSJN02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
Ambient													
JSUR01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSBP01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSRU03	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTED04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSNT01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSWH01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
NSAJ02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
NSEX01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES

[a]The geometric means were calculated using the 12 most recent fecal coliform values.

[b]The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

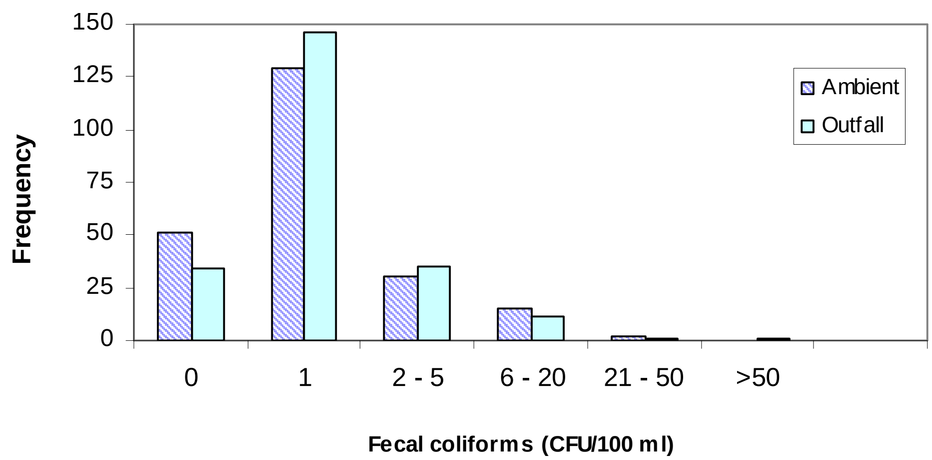


Figure 3-5. 2005-2007 Offshore Water Fecal Coliform Counts at 1 M

Fecal coliform counts at the Elliott Bay and Quartermaster Harbor stations tended to be higher more frequently than the other stations located in the Central Basin. The Elliott Bay stations had a higher proportion of values in the 6 to 50 CFU/100 ml range than the other stations. Table 3-4 shows the percentage of samples with various fecal coliform counts.

Enterococcus counts were similarly low with most surface samples (61%) having either no detectable levels or a value of 1 CFU/100 mL (17%). The highest enterococcus counts occurred in November 2006 at the West Point outfall station and December 2007 at the two Elliott Bay stations. Figure 3-6 shows enterococcus results for all offshore stations between 2005 and 2007 and Figure 3-7 shows enterococcus results plotted against concurrent fecal coliform values.

Table 3-4. Percentage of 2005-2007 Offshore Station Fecal Coliform Values in Various Categories

	Value (CFU/100 ml)						Total # of
Station Location	**0**	**1**	**2 - 5**	**6 - 20**	**21 - 50**	**>50**	**Samples**
Elliott Bay	0%	41.7%	29.2%	25%	4.2%	0%	72
Quartermaster H.	21.7%	45.6%	17.4%	15.2%	0.0%	0.0%	46
All other offshore	22.2%	66.5%	10.7%	0.3%	0.0%	0.3%	337

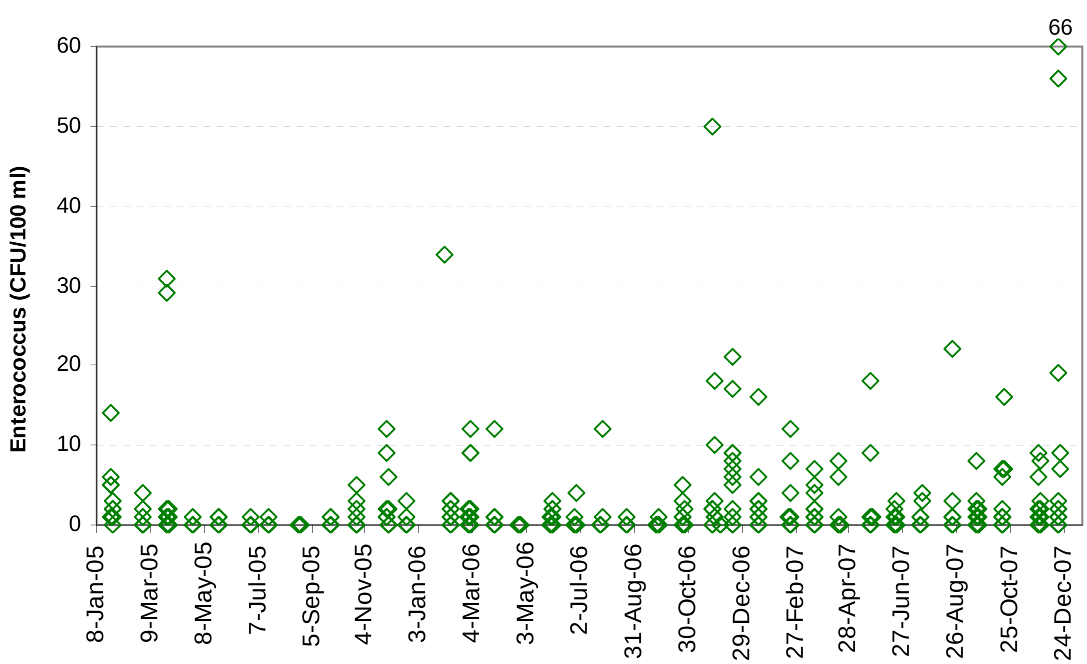


Figure 3-6. 2005-2007 Offshore Station Surface Water Enterococcus Counts (n=476)

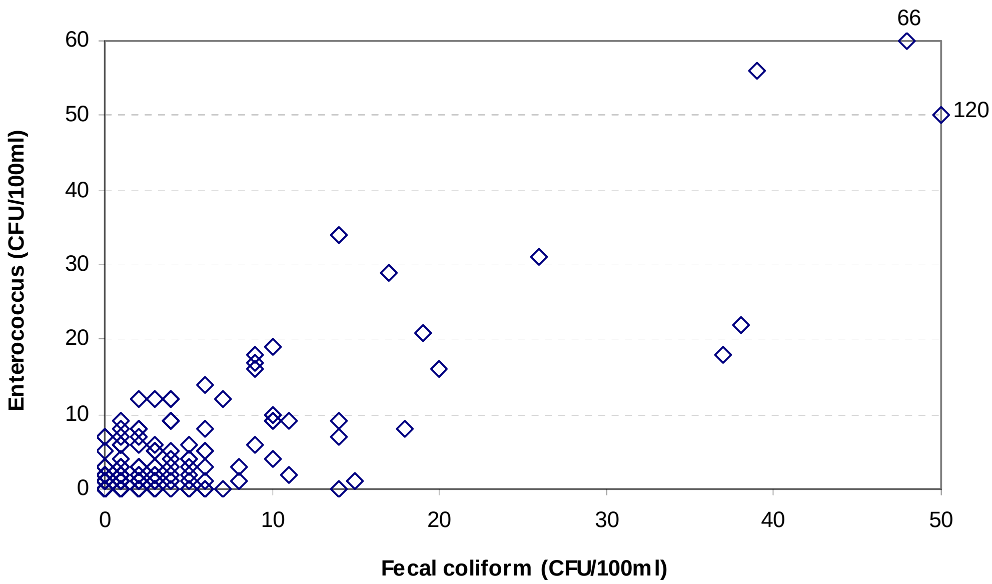


Figure 3-7. 2005-2007 Offshore Station Surface Water Paired Fecal Coliform and Enterococcus Counts

The low numbers of fecal indicator bacteria seen in offshore surface water samples between 2005 and 2007, as well as in previous sampling years, are explained by the low survival rates of fecal indicator bacteria in estuarine waters (Rhodes and Kator, 1988) in addition to distance from nearshore sources of bacteria. An EPA-sponsored study also supports these data results as it showed that the greatest single determinant of fecal indicator level is distance from the shoreline at which the sample was collected (Wymer *et al.*, 2005).

Beach Waters. Fecal coliform levels at beach stations are more variable than offshore stations due to their varying degrees of proximity to freshwater sources. Tables 3-5 through 3-7 provide a summary of station results between 2005 and 2007. Of the 15 stations monitored in all three years, 2 passed both standards all years (KSSN04 and MSSM05) and 3 failed either one of both standards all years (KSLU03, KSQU01, and LTEH02). Stations KSLU03, KSQU01, and LTEH02 have also consistently failed standards in the past as these sites are near a freshwater bacteria source. The other 10 stations varied from year to year with respect to standards compliance. As in previous years, no spatial patterns were detected in fecal coliform distributions from north to south. Additionally, no seasonal patterns were apparent. The highest fecal coliform counts were observed January of 2005 and 2006, particularly at stations near a freshwater source. The sampling dates in these months corresponded with major precipitation events within two days prior to sampling.

Eight stations were added to the beach sampling program in 2007 to increase spatial coverage within King County. Of the eight stations, five passed both fecal coliform standards and two failed both standards. The two sites that failed standards were Des Moines Creek Park and Redondo. The Redondo station, NTFK01, had consistently high bacteria counts from May through August. The geometric mean for NTFK01 was 40 CFU/100 mls and was calculated in

December using 12 sample results for the year. This geometric mean value was the highest of any of the marine beaches sampled between 2005 and 2007. The reason for high bacteria counts at this site is not evident but will be investigated further in 2009.

To rank the extent of fecal coliform levels at King County marine monitoring stations, a Frequency of Exceedence (FOE) Index was calculated for the all beach and offshore stations at which sufficiently consistent data had been collected for non-seasonally biased geometric mean determination. This index was modified from the Washington State Department of Health's fecal coliform index developed by Tim Determan. The FOE index is a weighted average that is calculated by tabulating the monthly geometric mean and ninetieth percentile (peak) values for each month on a yearly basis. Each value is then replaced by a weighting factor based on state water quality guidelines.

Table 3-5. Summary of 2005 Beach Station Compliance with Fecal Coliform Standards

Station	Meets Primary Contact Recreation												
	Moving Geometric Mean [a] (≤14 CFU/100 mL)												Peak [b] (43 CFU/100 mL)
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	
Outfall													
KSHZ03	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**N**	**N**	**NO**
KSSN04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSSN05	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSKR01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSJL01	**N**	**N**	**N**	**N**	**N**	Y	Y	**N**	Y	Y	**N**	**N**	**NO**
Ambient													
ITEDWARDSPT	Y	Y	Y	Y	Y	**N**	**N**	Y	Y	Y	Y	Y	**NO**
JSVW04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
ITCARKEEKP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KTHA01 [c]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSLU03	**N**	**N**	**N**	**N**	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
KSQU01	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
LTAB01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LTEH02	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
LSGY01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
LSFX01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
LSKS01	**N**	**N**	**N**	**N**	**N**	**N**	Y	Y	**N**	**N**	**N**	**N**	**NO**
LSHV01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSVW01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MTLD03	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MSSM05	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
NTAK01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES

[a]The geometric means were calculated using the 12 most recent fecal coliform values.

[b]The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

[c]Values were compared to the freshwater secondary contact fecal coliform standards.

Table 3-6. Summary of 2006 Beach Station Compliance with Fecal Coliform Standards

Station	Meets Primary Contact Recreation: Moving Geometric Mean [a] (≤14 CFU/100 mL) J	F	M	A	M	J	J	A	S	O	N	D	Peak [b] (43 CFU/100 mL)
Outfall													
KSHZ03	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES
KSSN04	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES
KSSN05	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
LSKR01	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES
LSKS04	--	--	--	--	--	--	--	--	--	--	--	**N**	**NO**
MSJL01	**N**	--	**N**	**N**	Y	Y	Y	Y	Y	Y	--	Y	YES
Ambient													
ITEDWARDSPT	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
JSVW04	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES
ITCARKEEKP	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
KTHA01 [c]	Y	--	Y	Y	Y	Y	Y	Y	**N**	**N**	--	**N**	**NO**
KSLU03	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
KSQU01	**N**	--	**N**	**N**	**N**	**N**	Y	Y	Y	Y	--	**N**	**NO**
LTEH02	**N**	--	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	--	**N**	**NO**
LSGY01	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
LSVW01	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	**NO**
MTLD03	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES
MSSM05	Y	--	Y	Y	Y	Y	Y	Y	Y	Y	--	Y	YES

[a]The geometric means were calculated using the 12 most recent fecal coliform values.

[b]The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

[c]Values were compared to the freshwater secondary contact fecal coliform standards.

The FOE index for each station is determined by calculating the arithmetic mean of the weighted factors for each station.

The weighting factors for calculating the FOE index are defined as follows:

Weighting factor	Definition
0	Value is less than 0.5X the water quality guideline
0.5	Value is greater than 0.5X and less than 1X the water quality guideline
1	Value is greater than 1X and less than 2X the water quality guideline
2	Value is greater than 2X and less than 3X the water quality guideline
3	Value is greater than 3X the water quality guideline

Table 3-7. Summary of 2007 Beach Station Compliance with Fecal Coliform Standards

Station	Meets Primary Contact Recreation												
	Moving Geometric Mean [a] (≤14 CFU/100 mL)												Peak [b] (43 CFU/100 mL)
	J	F	M	A	M	J	J	A	S	O	N	D	
Outfall													
KSHZ03	Y	Y	Y	Y	Y	Y	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
KSSN04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
KSSN05	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
LSKR01	Y	Y	Y	Y	Y	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
MSJL01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
Ambient													
ITEDWARDSPT	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
JSVW04	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
ITCARKEEKP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
KTHA01 [c]	**N**	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
KSLU03	Y	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
KSQU01	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	Y	**NO**
LTBD27	--	--	--	--	--	--	--	--	--	--	--	Y	YES
LTEH02	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
LSGY01	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSHV01	--	--	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
LSKS01	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**NO**
LSLT02	--	--	--	--	--	--	--	--	--	--	--	Y	YES
LSVW01	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	N	**NO**
MTEC01	Y	Y	Y	Y	Y	Y	Y	**N**	**N**	Y	Y	Y	**NO**
MTLD03	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	**NO**
MSSM05	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	YES
MRUW01	--	--	--	--	--	--	--	--	--	--	--	Y	YES
MTUJ01	--	--	--	--	--	--	--	--	--	--	--	**N**	**NO**
MSXK01	--	--	--	--	--	--	--	--	--	--	--	Y	YES
MTXA01	--	--	--	--	--	--	--	--	--	--	--	Y	YES
NTFK01	--	--	--	--	--	--	--	--	--	--	--	**N**	**NO**
NSJY01	--	--	--	--	--	--	--	--	--	--	--	Y	**NO**

[a]The geometric means were calculated using the 12 most recent fecal coliform values.

[b]The peak criterion refers to not more than 10% of the samples used to calculate the geometric mean exceeding this value.

[c]Values were compared to the freshwater secondary contact fecal coliform standards.

The results of ranking stations by the FOE index calculated between 2005 and 2007 are shown in Figure 3-8. The Redondo station, NTFK01, exhibited a twofold exceedence of the geometric mean bacteria guideline and a threefold exceedence of the peak guideline. The stations at Des Moines Creek Park (MTUJ01), Elliott Bay off Pier 48 (LTEH02), and Dumas Bay (NSJY01) also frequently exceeded the bacteria guidelines. All offshore stations, including the outfall stations, had the lowest FOE index for fecal coliforms.

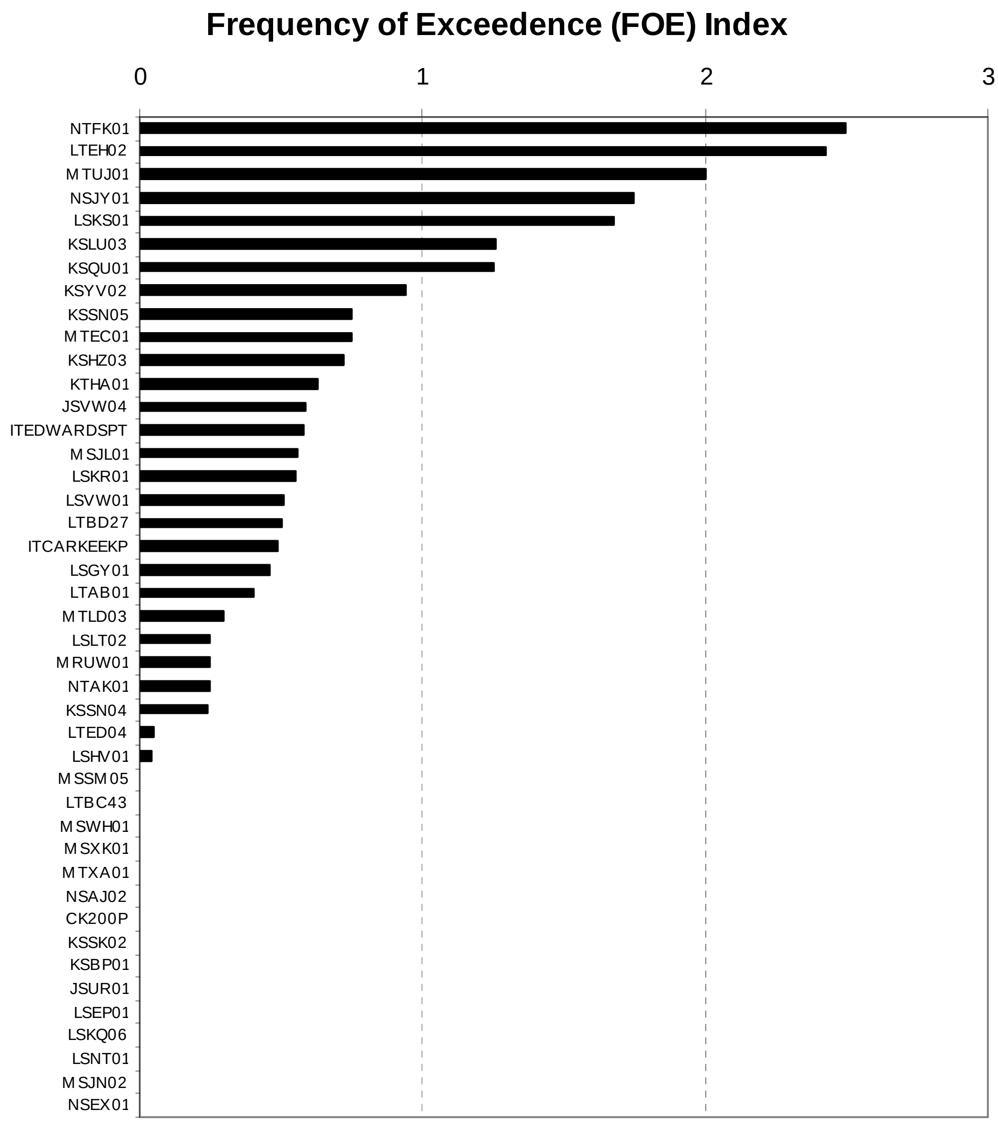


Figure 3-8. 2005-2007 FOE Index

Enterococcus counts at beach stations varied geographically and temporally. Values were generally highest in the winter months, although high counts were observed in the summer months at some locations. Correlation between fecal coliform and enterococcus counts varied considerably from location to location. Figure 3-9 shows enterococcus counts between 2005 and

2007 at all marine beach stations. The highest counts were seen at the Seattle waterfront station, LTEH02, followed by the Redondo station, NTFK01. The enterococcus counts at sites in the vicinity of outfalls were either similar to or lower than ambient stations. The counts near the outflow of Piper's Creek (station KSHZ03) were significantly higher than values at the site just north (ITCARKEEKP) and outside the influence of Piper's Creek.

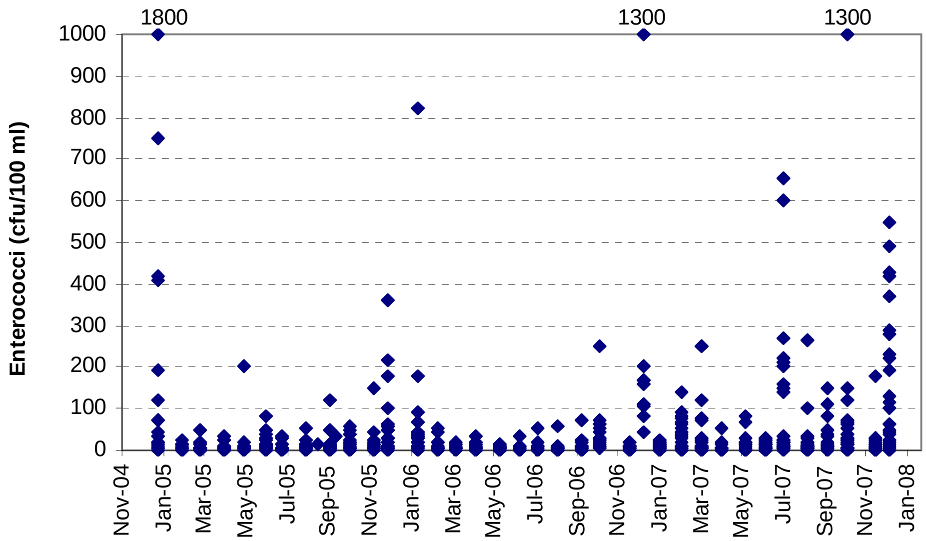


Figure 3-9. 2005-2007 Enterococcus Counts at Beach Stations

3.2.2 Water Temperature

Offshore Stations. Monthly temperature measurements were taken throughout the water column from the surface to just above the seafloor at each offshore station. For offshore stations sampled in 2005, 2006, and 2007, temperatures ranged from 4.6 to 19.5 °C (including data from all depths), with the greatest temperatures found at or near the surface. The mean temperature between 2005-2007 was 10.5 °C, which is similar to the mean temperature of 10.7 °C in 2004. Temperatures ranged in 2005 from 4.9 to 15.6 °C (mean = 10.7°C), in 2006 from 7.4 to 19.5 °C (mean = 10.6 °C), and in 2007 from 4.6 to 18.9 °C (mean = 10.2 °C). For all three years, the warmest temperatures were measured in surface waters in July. In 2006 and 2007, the warmest temperatures were seen at the shallow Quartermaster Harbor stations (NSAJ02 and MSWH01) and in 2005 at station KSBP01. The coldest temperature was also seen in Quartermaster Harbor.

The average air temperature for the month of July for 2005, 2006, and 2007 was 65.6, 67.5, and 67.8 °F, respectively. Air temperatures heavily influences sea surface temperatures and this relationship can be seen during the summer months in many of the offshore stations (Figures 3-10 and 3-11). This relationship was especially pronounced in 2006 due to the onset of El Niño conditions midway through the year. Figure 3-12 shows the changing steepness of the June thermocline over the course of the three years for stations CK200P, KSBP01, and LTED04.

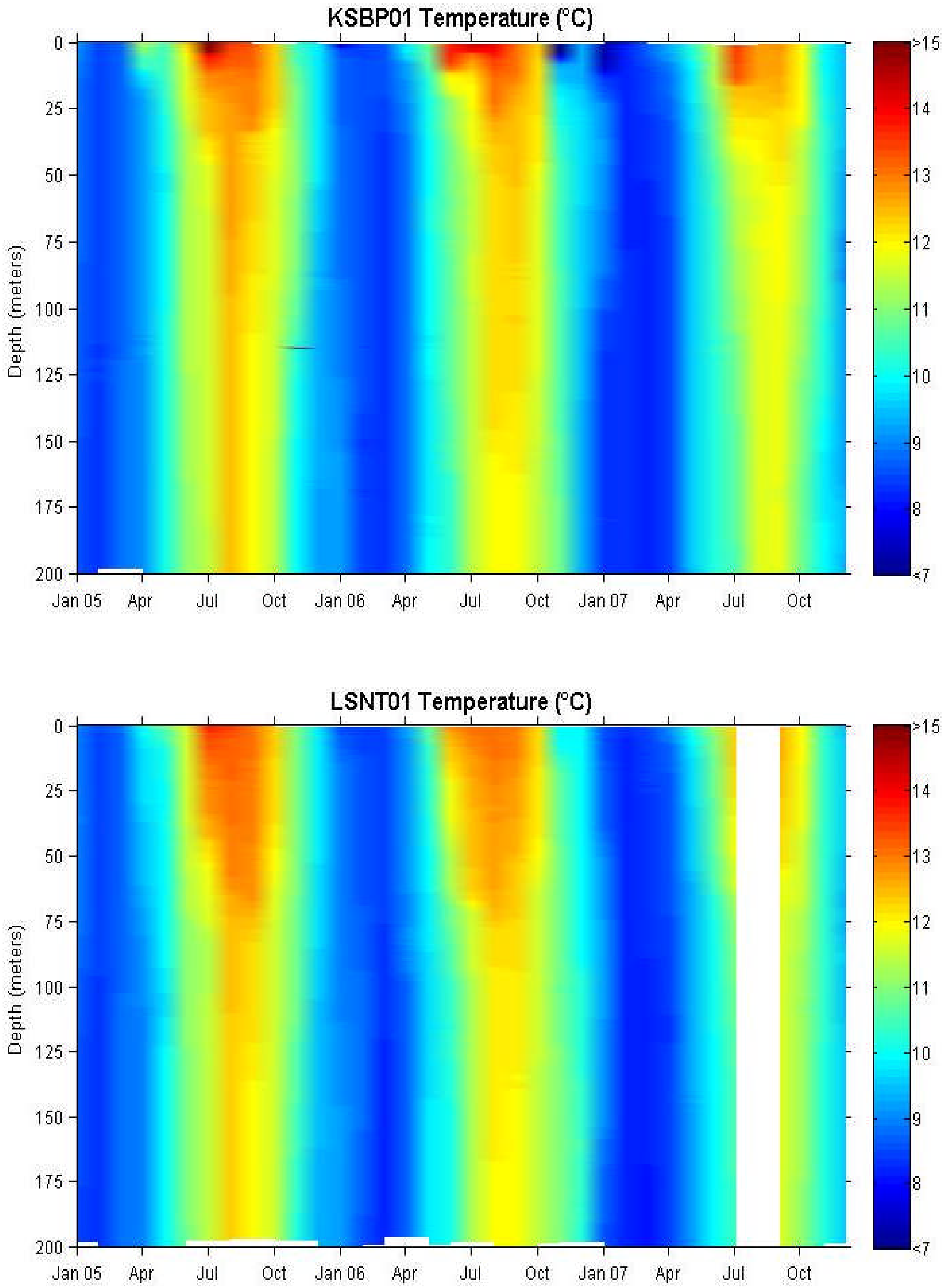


Figure 3-10. 2005-2007 Temperature Variations at Stations KSBP01 and LSNT01

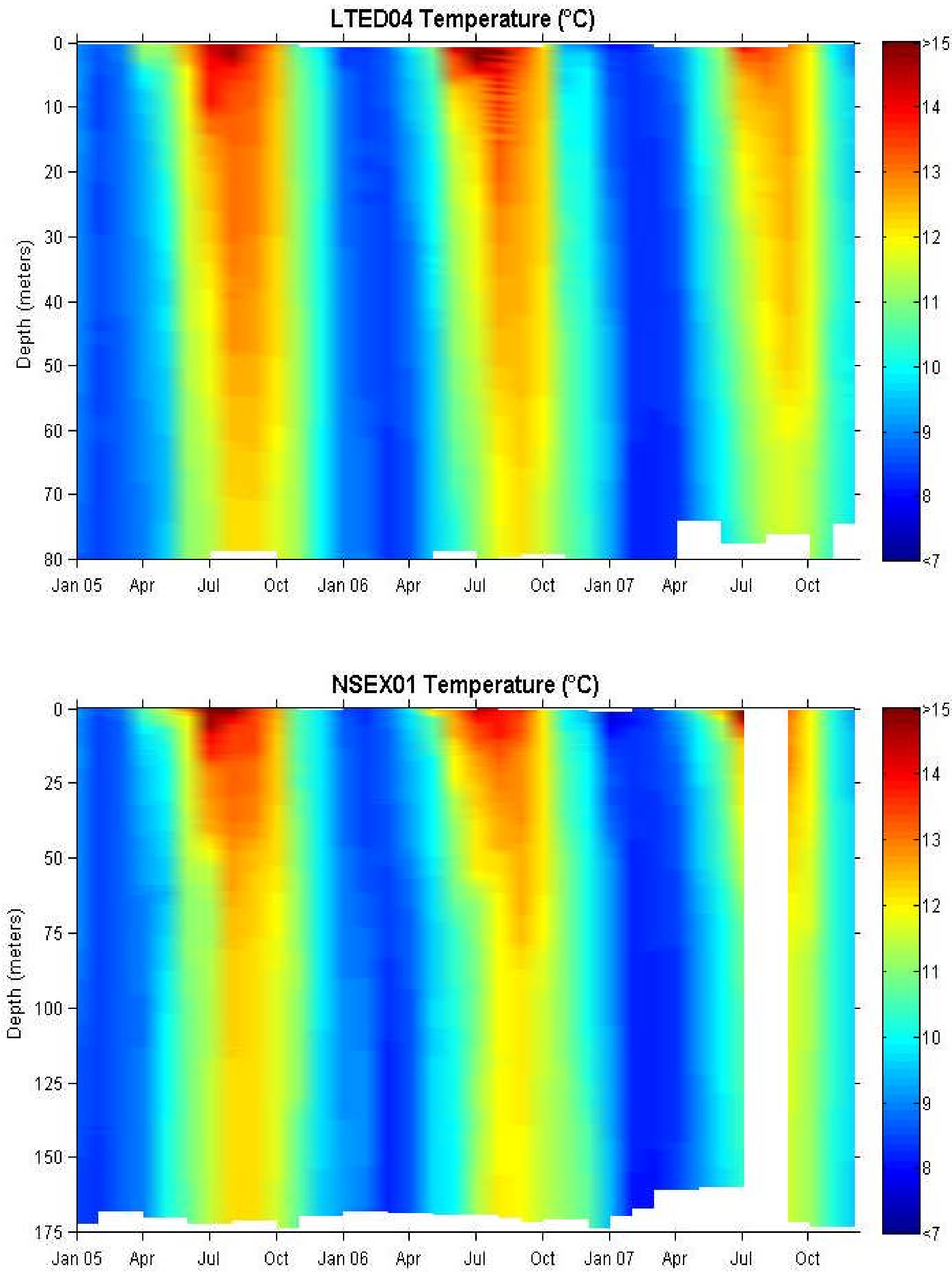


Figure 3-11. 2005-2007 Temperature Variations at Stations LTED04 and NSEX01

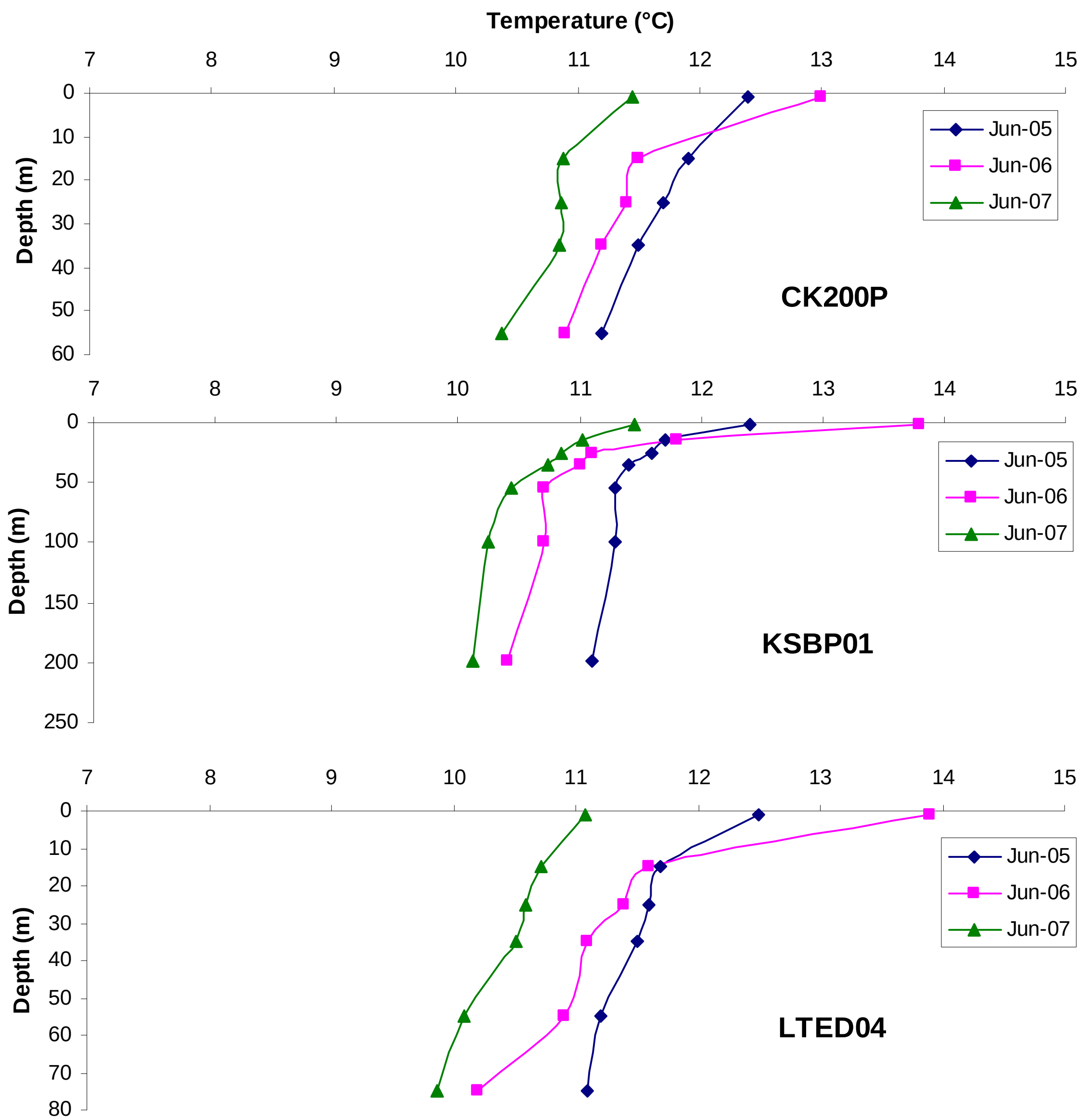


Figure 3-12. 2005-2007 June Temperatures for Selected Offshore Stations

In all three years, a seasonal thermocline (a depth range over which temperature decreases rapidly with depth) developed sometime between April and June at several of the offshore stations, particularly at stations CK200P and KSPB01. The thermoclines were much more pronounced in 2006 than in 2005 and 2007, likely due to El Niño conditions in mid-2006. By May, the thermoclines had developed more fully and extended deeper into the water column. By June, the temperature gradients in the upper water column had reached near maximum and began to decrease in July and August as the water temperature of the deeper water increased. By October the water column was well-mixed and thermoclines were no longer evident.

Water temperatures measured over the three year period shown in Figures 3-10 and 3-11 for stations KSBP01, LSNT01, and NSEX01 are typical for offshore waters in the Central Basin, excluding Elliott Bay. As shown in Figure 3-11, the warm waters in Elliott Bay during the summer months extend deeper through the water column than at other sample sites. With the exception of the summer months, the figures indicate a well-mixed water column throughout the year. Temperature values at discrete depths are provided in Appendix A.

***Beach Stations*.** Temperatures at beach stations ranged from 6.9 to 19.3 °C (mean = 11.6 °C) in 2005, from 7.6 to 19.2 °C (mean = 11.3 °C) in 2006, and from 4.1 to 18.3 °C (mean = 11.0 °C) in 2007. As shown in Figure 3-13, temperatures varied dependent upon location sampled. Temperature data for beach stations are provided in Appendix A.

Between 2005 and 2007, water temperatures were lower at the Vashon Island station MSJL01, which is influenced by freshwater runoff from Gorsuch Creek. Station KSQU01 located at the exit of the Lake Washington Ship Canal near Shilshole Bay had some of the highest overall water temperatures. This station is highly influenced by freshwater exiting Lake Washington and Lake Union through the Ship Canal.

During the winter months, the coldest temperatures were observed at stations with the most freshwater input: Shilshole Bay (KSQU01), Piper's Creek (KTHA01), and the Seattle Waterfront (LTEH02). In January 2007, the Burton Acres station (MSXK01) in Quartermaster Harbor had the coldest temperature observed of 4.1 ^{o}C. Ice was observed floating on the surface in inner Quartermaster Harbor when samples were collected in January 2007.

During the summer months, the two Vashon Island stations generally had the lowest temperatures. Although the Shilshole Bay station had colder temperatures during the winter months, this station had some of the highest temperatures during the summer months. As stated above, this station is highly influenced by the warm Lake Washington waters exiting through the Ship Canal.

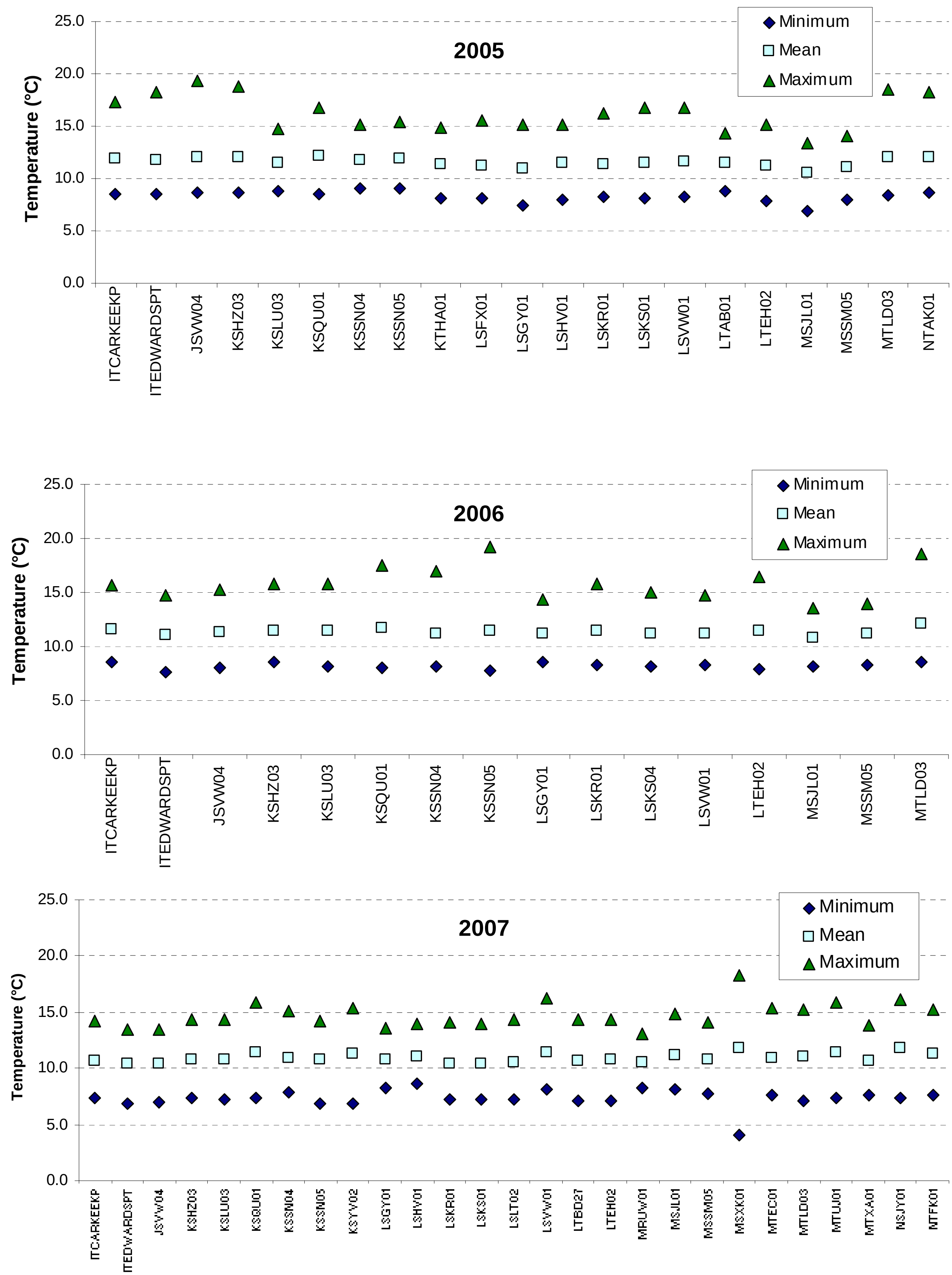


Figure 3-13. Water Temperature at Beach Stations from 2005 to 2007

3.2.3 Salinity and Density

Offshore Salinity. Salinity measurements were collected throughout the water column at all offshore stations. For offshore stations sampled in 2005, 2006, and 2007, salinities ranged from 14.85 to 31.06 on the Practical Salinity Scale (PSS), with a mean salinity of 29.65 PSS. Salinities ranged in 2005 from 26.86 to 30.97 PSS (mean = 29.91 PSS), in 2006 from 23.60 to 31.08 PSS (mean = 29.57 PSS), and in 2007 from 14.85 to 30.74 PSS (mean = 29.47 PSS). Low salinity values occurred in surface waters of various stations for all three years, where river input and heavy rain events can be strong influencing factors. The highest salinities for all three years were found offshore at depths greater than 150 m during the month of October. This may be attributed to the increased input of salty deep oceanic water upwelled along the Pacific coast and entering Puget Sound during late summer and fall. Salinity values at discrete depths are provided in Appendix A for offshore stations.

Salinities varied due to seasonal influences as shown in the vertical salinity profiles for stations CK200P and KSSK02 (Figure 3-14). Apart from the surface layer where wide ranges were observed, salinity showed little variability over the depth profile indicating a well-mixed water column. In 2005, the lowest salinities were found in the surface waters of Elliott Bay (stations LTBC43 and LTED04) primarily due to freshwater runoff from the Duwamish River following rain events and summer snow melt. In 2006, the lowest salinities occurred at the northern Central Basin stations (KSBP01, KSSK02, JSUR01). Station KSBP01 (Jefferson Head) had a salinity value of 23.60 PSS in November 2006, which can be attributed to the 15.63 inches of rain experienced that month. Stations KSSK02 and JSUR01 (West Point Outfall and Point Wells) had salinity values of 24.95 and 25.53 PSS, respectively, in early February 2006 which can also be attributed to large rain events. A total of 11.65 inches of rain was recorded in January 2006, with over 3 inches falling within the last four days of the month.

In 2007, the lowest salinities occurred at station KSRU03 (outer Salmon Bay) which is located on the marine (west) side of the Hiram Chittendum Locks. Salinities were recorded as low as 14.85, 16.28, and 16.63 PSS in the months of March, April and December, respectively, which is due to input of freshwater from Lake Washington and rain events during those months. Besides station KSRU03, low salinities occurred at the usual Elliott Bay stations (LTBC43 and LTED04). Generally, salinities were highest from August to December, likely from an increased contribution of saltier, deep Pacific Ocean water from upwelling along the outer coast during late summer in combination with a decrease in freshwater input from rivers and runoff.

Salinity profiles between 2005 and 2007 are shown in Figures 3-15 and 3-16 for four selected stations throughout the Central Basin. Overall, the figures indicate a well-mixed water column throughout much of the year, particularly from November through January. Development of a halocline (a rapid change in salinity with depth) occurs in the winter and spring for reasons described previously. The halocline is more defined at station LTED04 due to the greater influence of freshwater at this location compared to the other three stations. A strong decrease in salinity can be seen in January of 2006 at all four stations due to major rain events that month. The cycle of coastal upwelling and its influence upon the waters of Puget Sound is seen as a deep, salty signal in late summer and fall of each year.

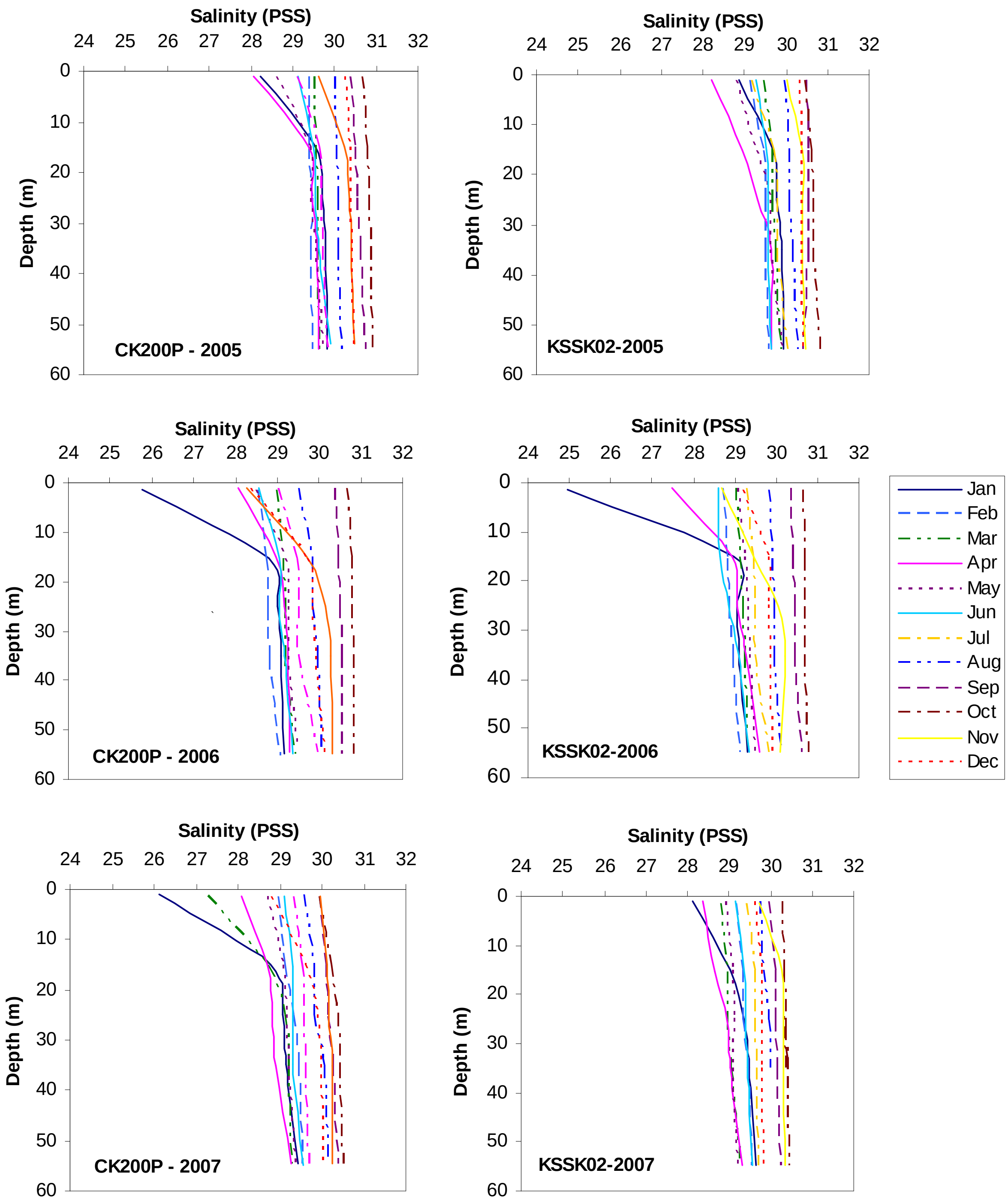


Figure 3-14. 2005-2007 Vertical Salinity Profiles from Stations CK200P and KSSK02

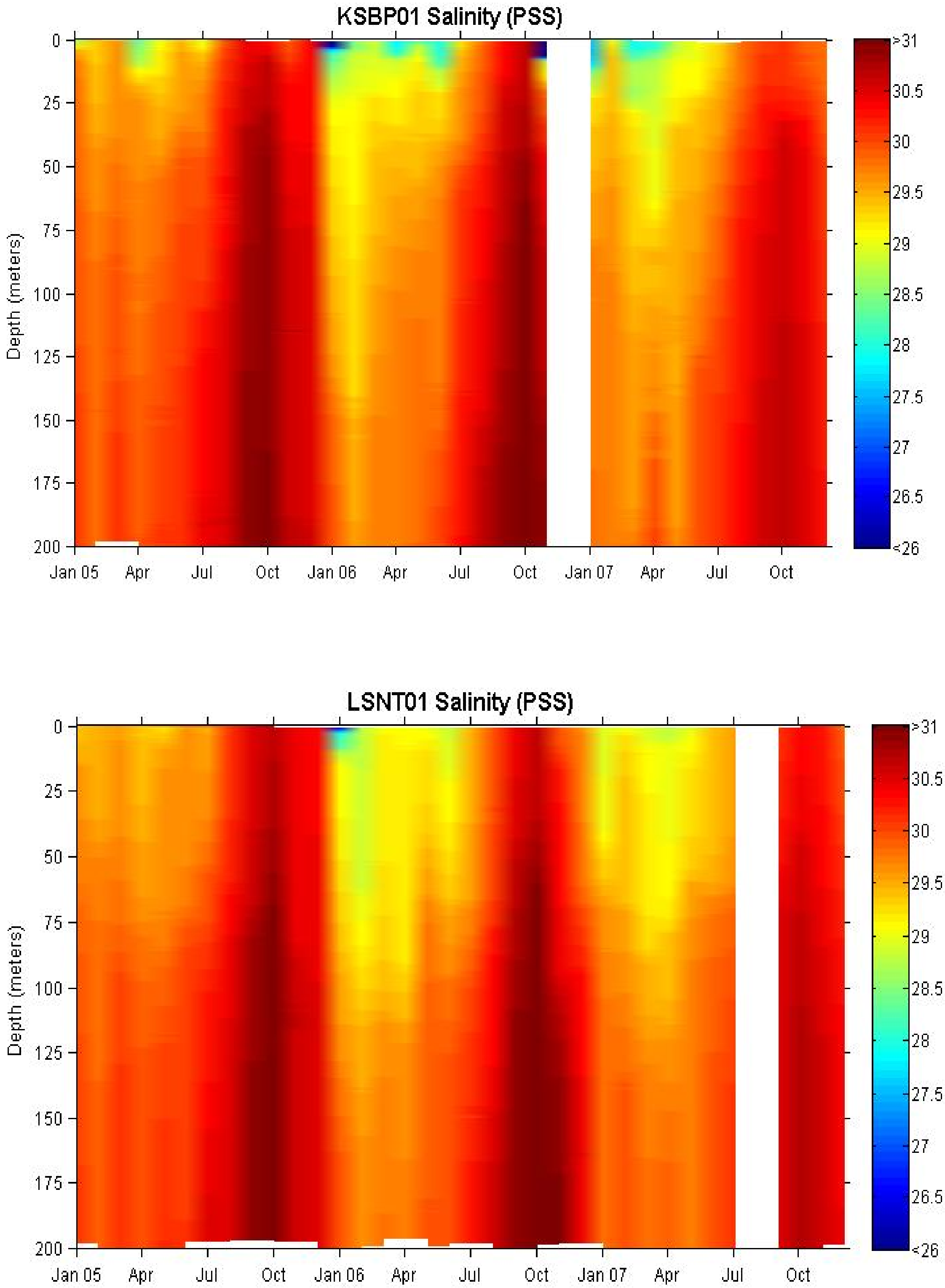


Figure 3-15. Salinity Variations at Stations KSBP01 and LSNT01 from 2005-2007

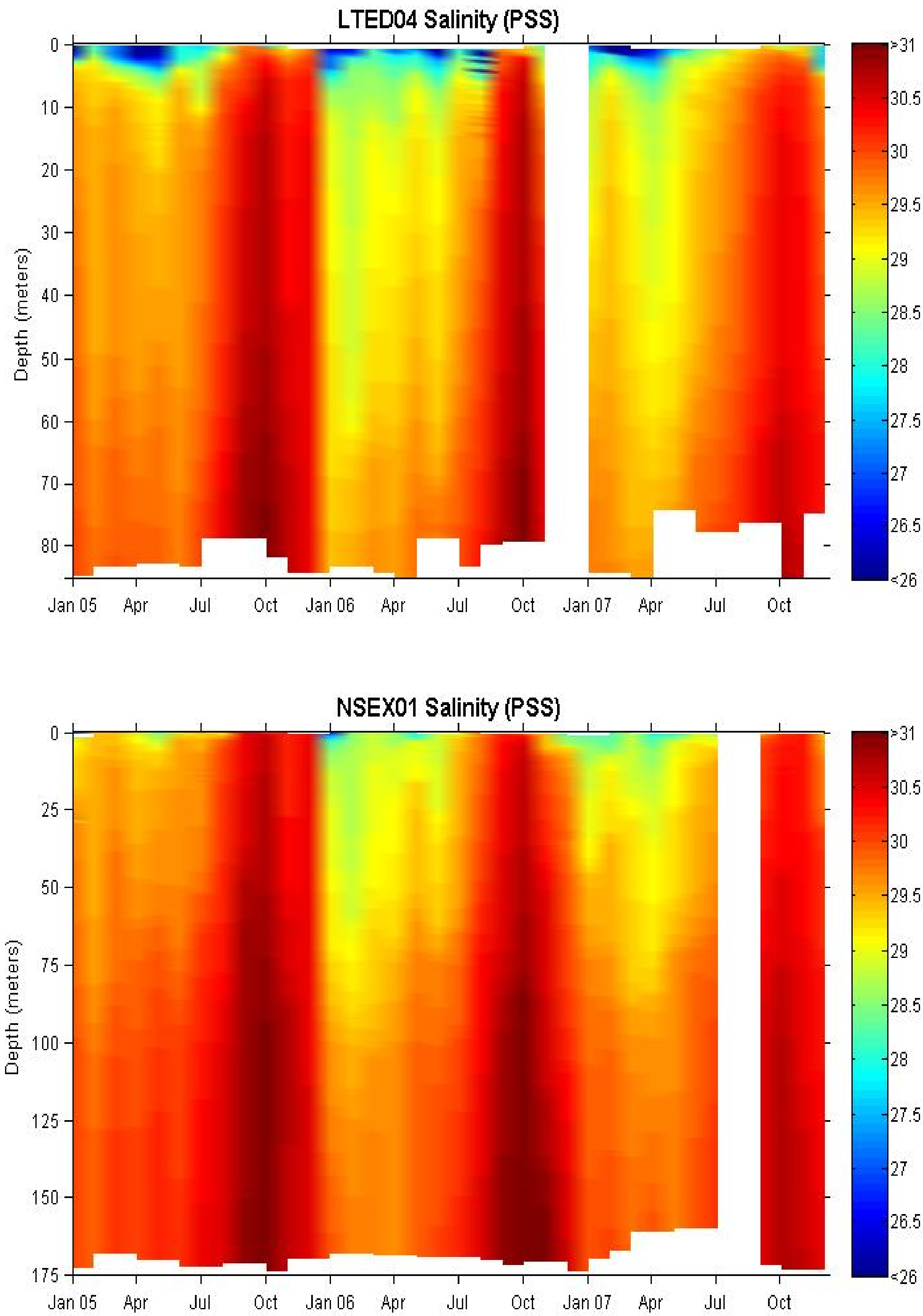


Figure 3-16. Salinity Variations at Stations LTED04 and NSEX01 from 2005-2007

Beach Salinity. Salinity at beach stations ranged from 23.07 to 30.66 PSS (mean = 29.12 PSS) in 2005, from 8.79 to 30.62 PSS (mean = 27.25 PSS) in 2006, and from 9.79 to 30.44 PSS (mean = 27.70 PSS) in 2007. Figure 3-17 shows salinities at all beach stations between 2005 and 2007 as well as the range in salinities at individual stations for 2007. The number of sampling stations increased in 2006, which is reflected in the top figure. Salinities were lowest at stations near a freshwater source. The lowest salinity in 2006 was at station KSQU01 located at the exit of the Lake Washington Ship Canal and in 2007, the lowest salinity was found at station NSJY01 (Dumas Bay Park). Low salinities are routinely measured at stations KSQU01 and KSHZ03 due to their proximity to freshwater sources. There was no notable pattern in salinity values from north to south, other than variations due to freshwater inputs. Seasonal changes in salinity showed highest values from September to November and decreasing values in December due to increased precipitation and runoff, reaching a minimum in February and March. Salinity data for beach stations is provided in Appendix A.

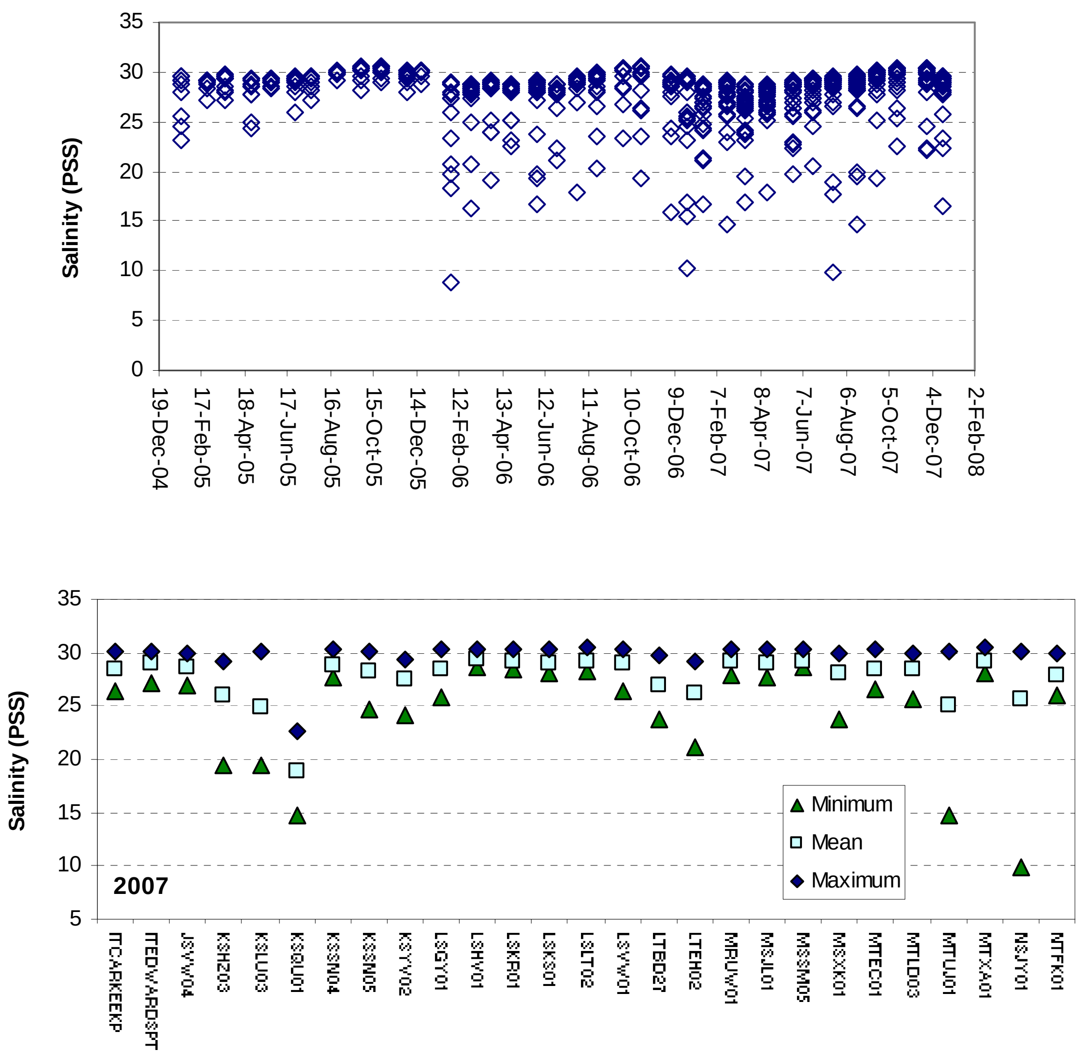


Figure 3-17. Salinity at Beach Stations in 2005, 2006, and 2007

Offshore Density. Water density is a function of both salinity and temperature, with density increasing with higher salinity and lower temperature. Salinity tends to be a stronger influence than temperature on density structure in Puget Sound. Density stratification within the water column impedes vertical mixing and can, therefore, affect the concentration of substances found at differing depths in the water column. Figure 3-18 shows the vertical density profiles for offshore stations CK200P and KSBP01. In general, density stratification is strongest during the summer due to increased solar heating and freshwater runoff from snow melt, both of which lead to a decrease in surface water density. Stratification weakens in the winter due to reduced solar influence and increased mixing of the water column.

Due to the seasonal cycles of temperature and salinity in Puget Sound, a light density phase, particularly at surface depths, occurs during the spring and summer months (Figures 3-19 and 3-20). This is followed by a dense phase in fall and winter. Exceptions to this trend were seen in January 2006 and November 2006, where instead of a typical dense phase a lighter dense phase occurred. These low density values are attributed to the heavy rain events during those months in 2006. Densities at the Elliott Bay stations indicate that the water column exhibits strong-intermittent stratification, with stratification occurring throughout most of the summer. Densities at other Central Basin locations show that the stratification intensity only occurs on a moderate and infrequent basis. Density values at discrete depths are provided in Appendix A for offshore stations.

3.2.4 Dissolved Oxygen

Physical processes affecting dissolved oxygen (DO) distributions in Puget Sound include the input of fresh and ocean water, stratification intensity within the water column, circulation patterns and mixing regimes, and the exchange of oxygen across the air-sea interface. Biological activity (e.g. photosynthesis, respiration) and chemical oxidation also affect ambient levels of DO and its distribution within the physical system both vertically and horizontally. Throughout the year, the surface marine waters remain well oxygenated. However, the water below the photic zone is less oxygenated due to the consumption of oxygen by the remineralization of organic material descending through the water column from the photic layer. Low dissolved oxygen concentrations can occur when organic matter is decomposed in waters that do not mix to the surface where aeration with atmospheric oxygen can occur. Upwelled deep waters and deep waters with overlying high organic production can have naturally occurring low dissolved oxygen concentrations.

Dissolved oxygen measurements were made throughout the water column from the surface to just above the seafloor at each offshore station. Values at discrete water depths are provided in Appendix A. Dissolved oxygen concentrations ranged in 2005 from 4.9 to 15.1 mg/L (mean = 7.5 mg/L), in 2006 from 4.1 to 15.4 mg/L (mean = 7.5 mg/L), and in 2007 from 3.6 to 12.1 mg/L (mean = 7.6 mg/L). The range and mean values observed in 2005, 2006, and 2007 are similar to measurements made in previous years. A DO concentration of 5.0 mg/L is the level at which biological stress may be induced by low dissolved oxygen and areas where DO concentrations are below 5.0 mg/L should be closely examined. DO levels for all offshore stations in 2005 were

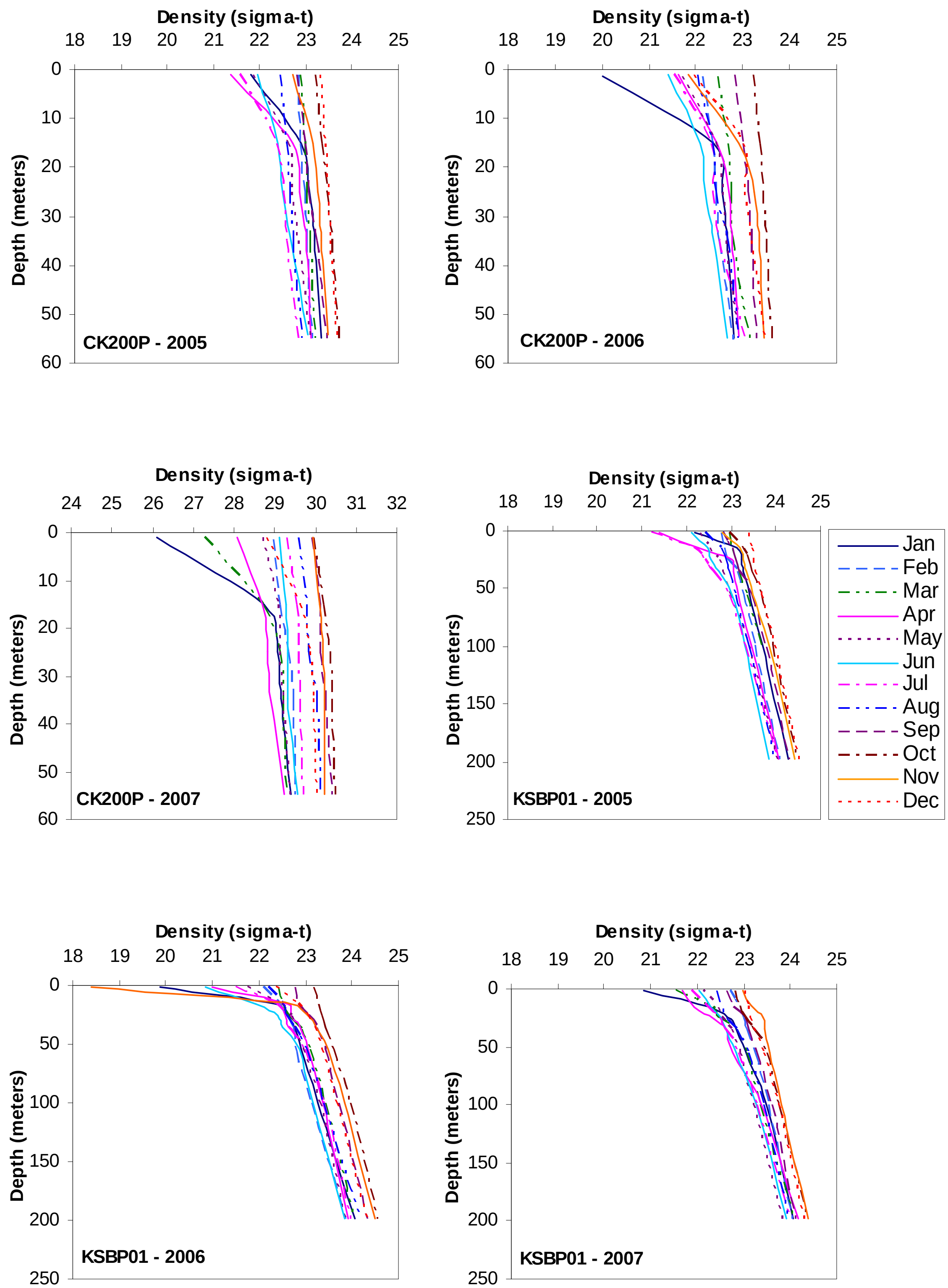
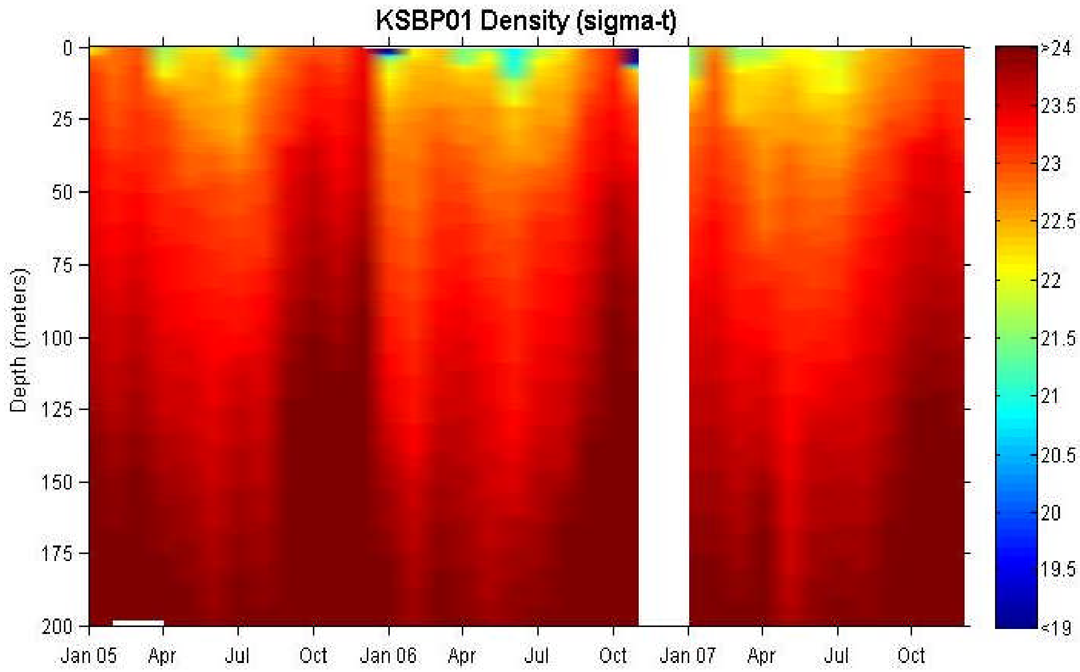


Figure 3-18. 2005-2007 Vertical Density Profiles from Stations CK200P and KSBP01



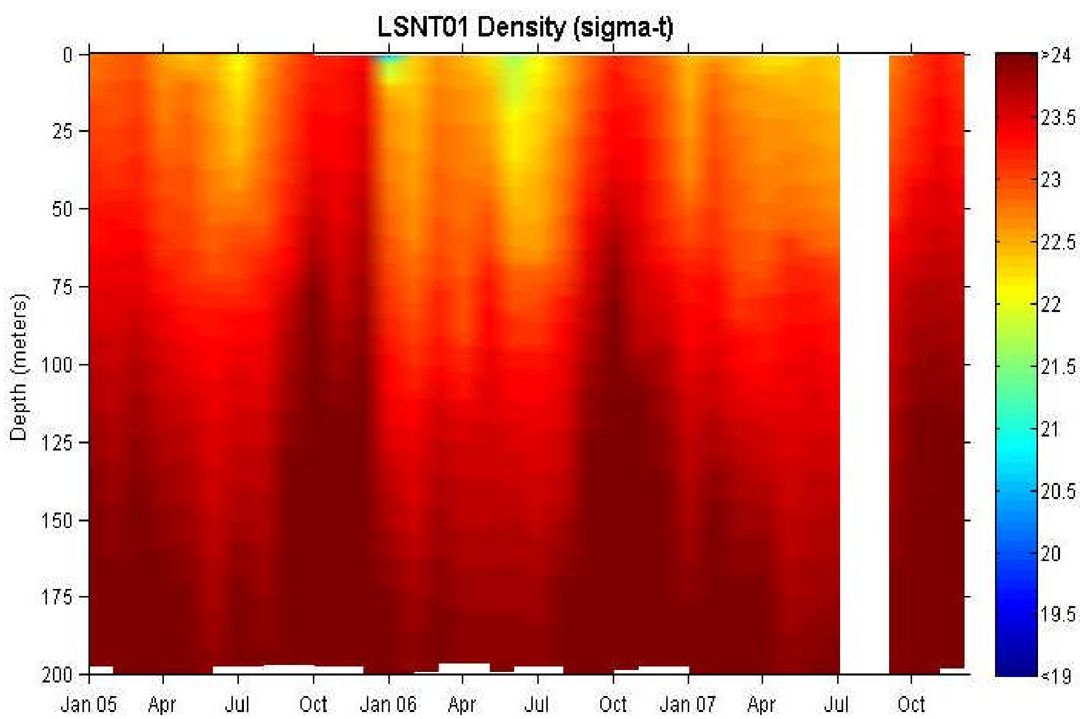


Figure 3-19. Density Variations at Stations KSBP01 and LSNT01 from 2005-2007

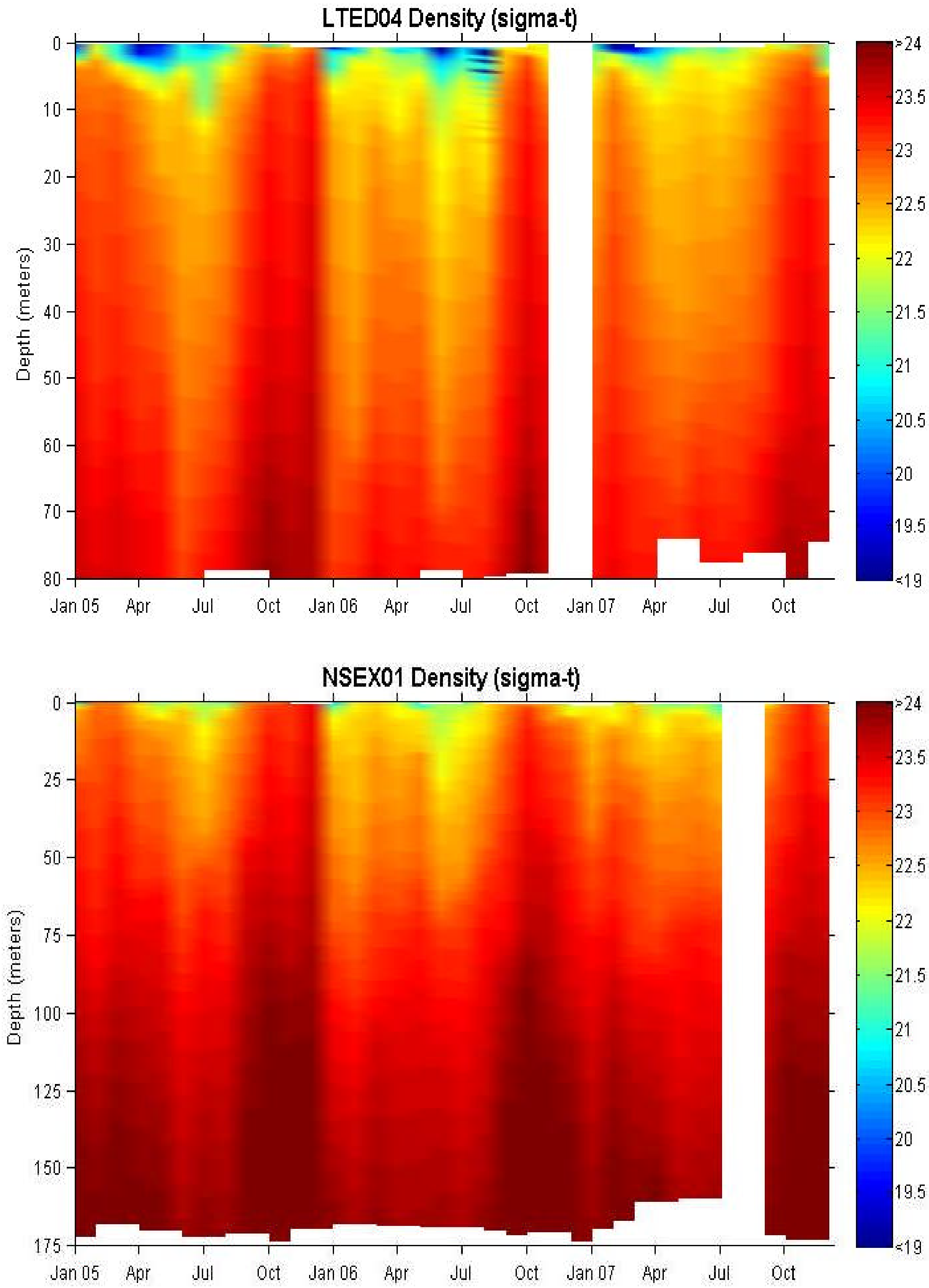


Figure 3-20. Density Variations at Stations LTED04 and NSEX01 from 2005-2007

at or above 5.0 mg/L. The minimum values in 2006 and 2007 (most importantly, the 3.6 mg/L in 2007) were found at stations MSWH01 and NSAJ02, both located in Quartermaster Harbor.

These especially low levels of dissolved oxygen are of great concern and are the reason monitoring stations were placed in Quartermaster Harbor. Low levels of DO in this area may be in part due to the shallow depths and the fact that it is a harbor, where flushing and introduction of oxygenated water is limited. Other than the previously mentioned exceptions, minimum dissolved oxygen levels were observed below approximately 50 m in late summer and fall during all three years. This is a result of the seasonal influx of Pacific Ocean water, which has low ambient concentrations of DO, into deep Puget Sound coinciding with the oxidation of organic matter from spring, summer, and early fall phytoplankton blooms. Increased water column density stratification in the spring and summer also contributes to low DO levels in the deeper layers as it impedes vertical mixing. A surface/subsurface DO maximum was seen in spring and summer at stations in the upper 35 m approximately. The maximums in dissolved oxygen correspond with maximums in chlorophyll-a concentration, temporally and spatially, and may therefore be attributed to primary productivity.

Seasonal DO variations from 2005-2007 at stations KSBP01, LTED04, LSNT01, and NSEX01 are shown in Figures 3-21 and 3-22. Patterns due to the input of low-oxygenated Pacific water and consumption of oxygen by bacterial respiration over the late summer/fall months are evident in the deep layers of the water column. The production of oxygen through primary production in the upper layers during the late spring and summer is also discernable in each year. As the density gradient break down in the fall and winter, the water column becomes well-mixed with little variability in DO levels from surface to depth.

Dissolved oxygen concentrations in Puget Sound are generally above 7.0 mg/L in the late winter and early summer months at all depths and locations sampled. Throughout the year, DO levels sometimes fell below 5.0 mg/L (as previously discussed above), the level at which biological stress may be induced by low DO (NOAA, 1998). During summer and fall, a seasonal influx of deep oceanic water low in DO results in naturally occurring DO concentrations below 7.0 mg/L. Figure 3-23 shows the seasonal variation in DO concentrations for 2005, 2006, and 2007, respectively, at both ambient and outfall offshore sites at discrete depths. At the 7.0 mg/L standard level, little difference was observed between ambient and outfall sites, with a higher percentage of samples above the standard seen at outfall sites. This indicates that effluent from the outfalls is not affecting dissolved oxygen concentrations.

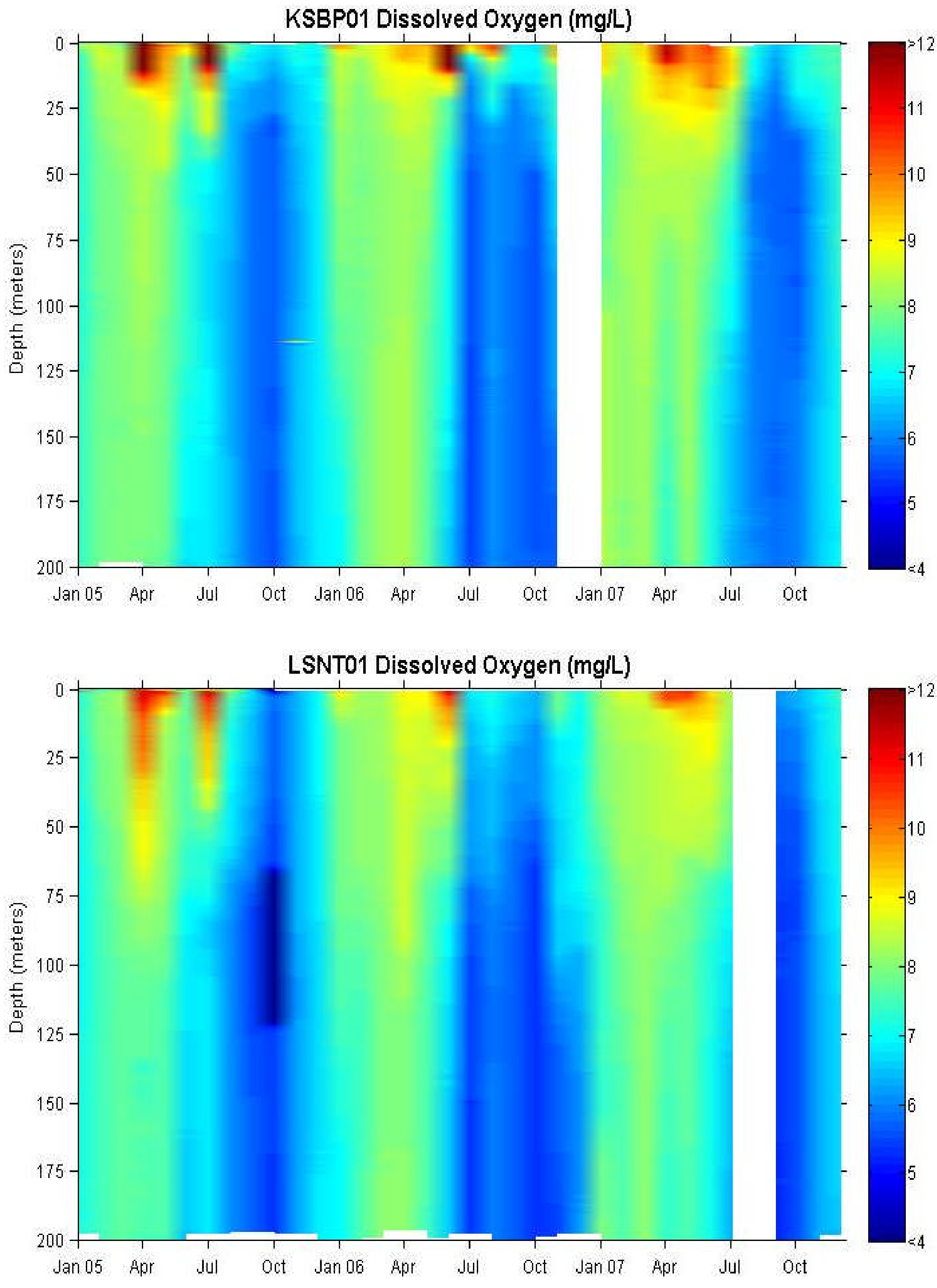
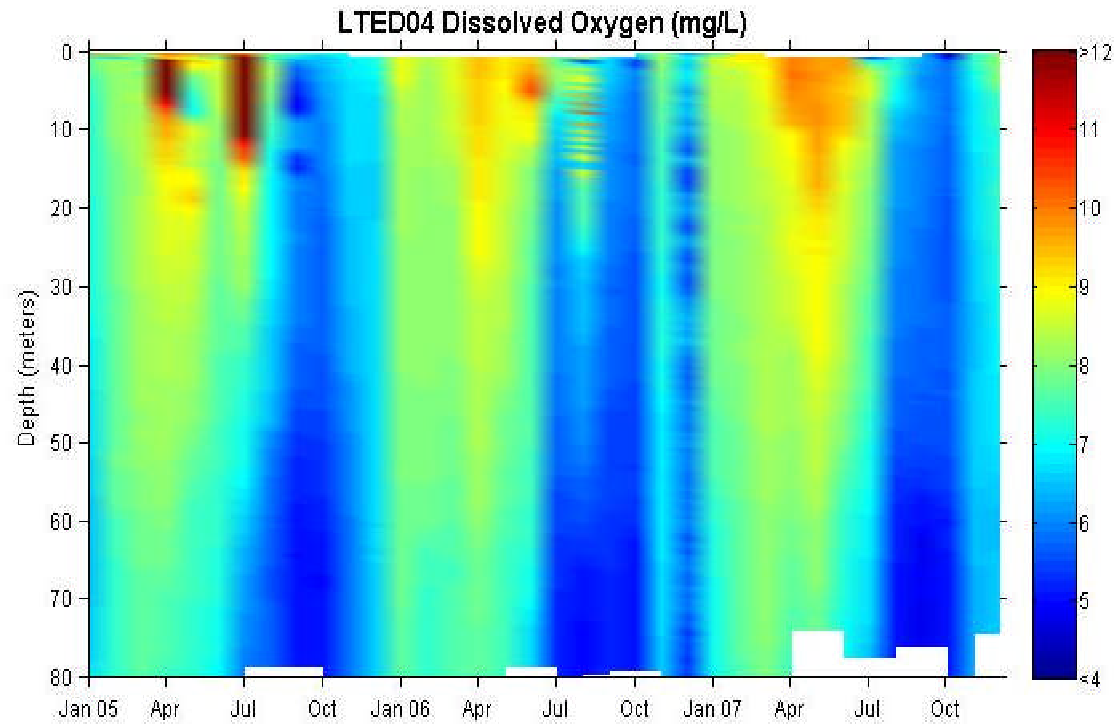


Figure 3-21. Dissolved Oxygen at Stations KSBP01 and LSNT01 from 2005-2007



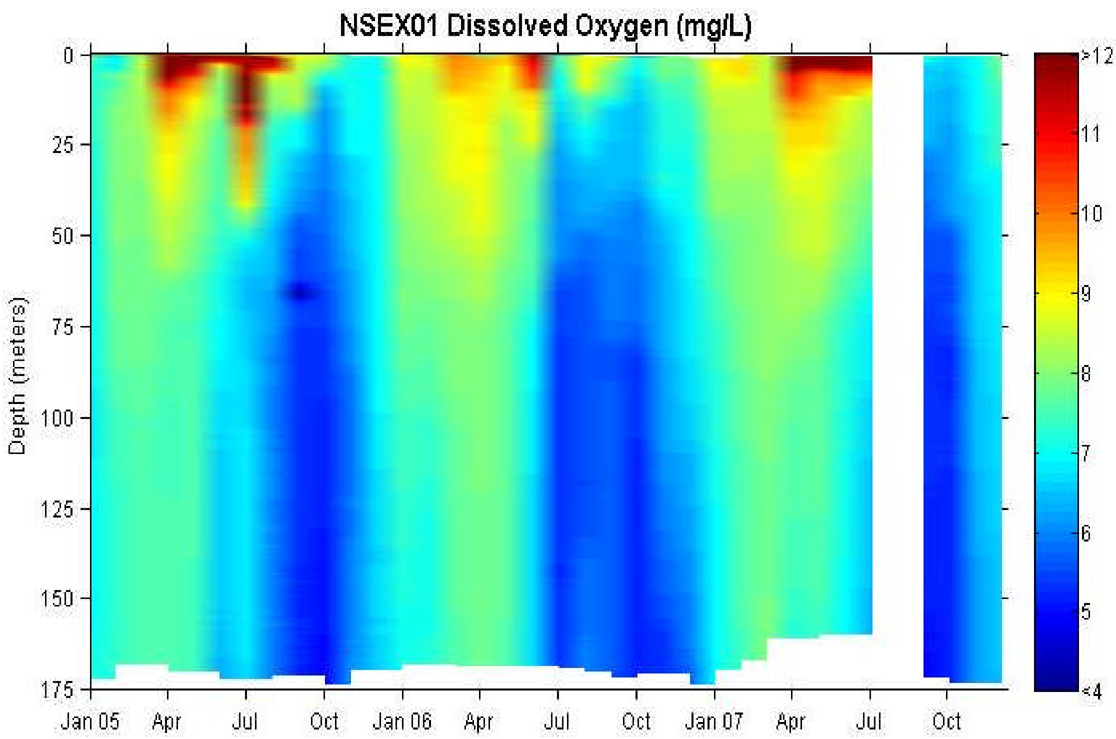


Figure 3-22. Dissolved Oxygen at Stations LTED04 and NSEX01 from 2005-2007

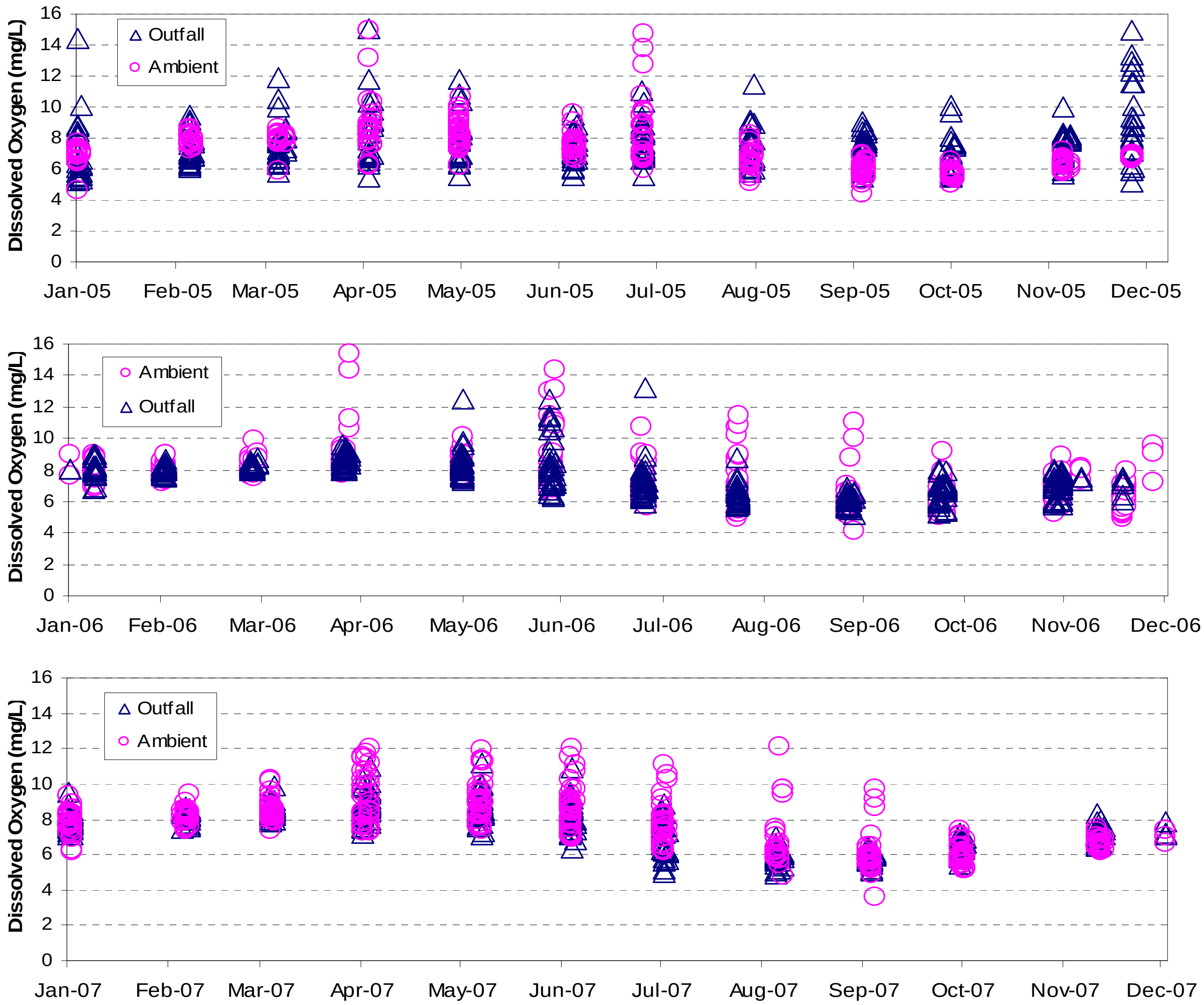


Figure 3-23. 2005-2007 Dissolved Oxygen Concentrations at Discrete Depths Ranging from 1-200 meters

3.2.5 Transparency and Light Intensity

Secchi Disk. Secchi disk measurements were taken at all offshore stations on a monthly basis in order to evaluate the transmission of visible light through the water at the surface. These measurements of water clarity provide an approximate transparency value and are taken by lowering the disk into the water and recording the depth at which it is lost to sight. The greater the Secchi depth value, the greater the water transparency. Environmental factors that influence Secchi transparency include turbidity, riverine input, runoff, shoreline erosion, resuspension of bottom sediment, and phytoplankton biomass. Secchi disk values ranged from 2.1 to 13.0 m in

2005, from 2.0 to 15.0 m in 2006, and from 1.7 to 15.0 m in 2007. Table 3-8 lists the minimum, maximum, and average Secchi depths by station for all three years. As in previous years, there was no difference in transparency between ambient and outfall stations. In general, minimum values were observed late spring/early summer due to phytoplankton abundance, and maximum values were observed in late summer/early fall due to reduced productivity and lower rainfall. Monthly Secchi transparency depths, along with the mean chlorophyll-*a* levels, for stations CK200P (outfall), KSBP01 (ambient), and LTED04 (ambient) during 2005 to 2007, are presented in Figure 3-24. Secchi depths were fairly constant from January through March in all three years. In April 2005, June 2006, and April 2007, the first phytoplankton bloom of the year occurred during which a corresponding decline in Secchi transparency was seen. Additional blooms were seen in July 2005, August 2006, and June 2007 which also had low Secchi transparency values associated with them. In September 2006, a notable increase in Secchi transparency was seen at all three stations, which is due to calm weather and low to non-existent chlorophyll-*a* levels. In general, lower Secchi depths correspond to higher chlorophyll-*a* values. An exception to this trend can be seen January and November of 2006, which both had low Secchi transparency values during times of low chlorophyll-*a* values. These dips in Secchi depth measurements were most likely due to the rough weather and heavy rains that occurred during those months. All Secchi measurements from 2005 to 2007 can be found in Appendix A.

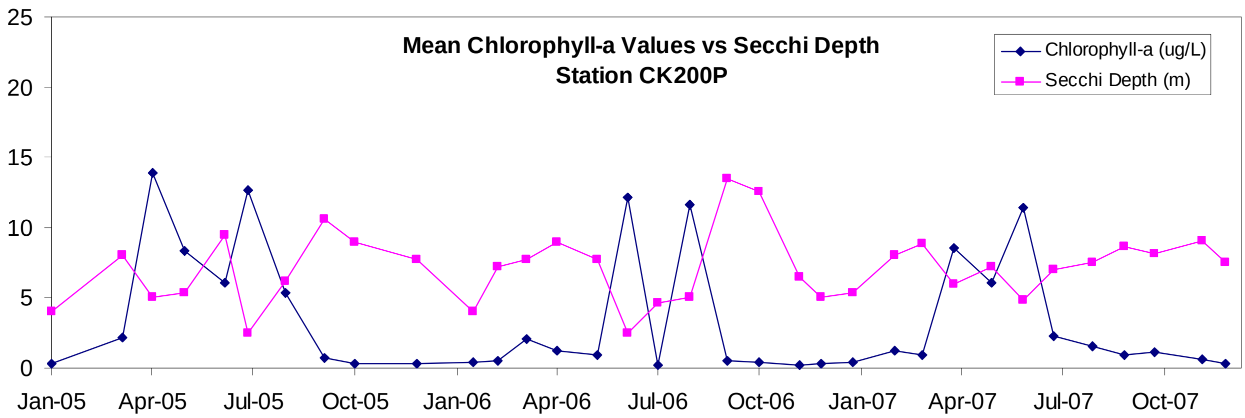
Turbidity and Transmissivity. Turbidity is another measure of water clarity but differs from Secchi disk measurements in that it is an expression of the amount of light scattered or reflected (the lower the turbidity value, the more transparent the water). Dissolved and suspended solids (including detritus, plankton, and particulates), can affect the water's optical properties resulting in high turbidity values. Wind and waves can indirectly increase turbidity by stirring up particulates in the water. Turbidity measurements were taken at offshore stations in 2005. Turbidity values ranged from less than 0.5 (MDL) to 5.6 Nephelometric Turbidity Units (NTU). The maximum value was measured in March at station JSUR01 at 173 m. The next five out of six highest turbidity values were also measured at a depth equal to or greater than 170 m. The highest values were generally found at surface and bottom depths, where the amounts of dissolved and suspended solids were greatest.

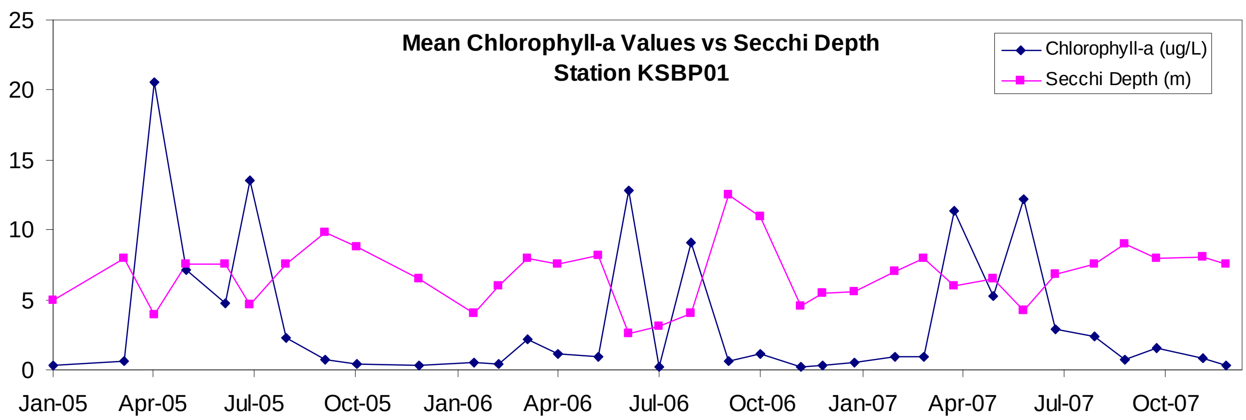
Starting in 2006, a change in instrumentation was made from turbidity to transmissivity. Transmissivity measures the percent of light present at a given depth. Transmissivity values ranged from 43 to 88% light in 2006 and from 52 to 87% light in 2007. Transmissivity is inversely related to turbidity, so that the lowest transmissivity values were found at surface and bottom depths, and the highest around 15 to 35 m. Higher turbidity results in a lower transmissivity measurement. Appendix A contains turbidity and transmissivity values for all offshore stations.

Table 3-8. Minimum, Maximum, and Average Secchi Disk Depths (m) by Station for 2005-2007

Year	Station	Mean Secchi Depth (m)	Minimum Secchi Depth (m)	Maximum Secchi Depth (m)
2005				
	CK200P	6.8	2.5 (Jul)	10.6 (Sep)
	JSUR01	6.9	3.2 (Apr)	11.0 (Oct)
	KSBP01	6.9	3.9 (Apr)	9.8 (Sep)
	KSSK02	6.9	3.6 (Apr)	10.0 (Sep)
	LSEP01	7.3	3.5 (Apr)	12.8 (Sep)
	LSKQ06	7.4	4.0 (Jul)	11.5 (Sep)
	LSNT01	7.6	4.7 (May)	10.5 (Sep)
	LTBC43	6.3	2.1 (Jan)	10.0 (Sep)
	LTED04	6.3	2.7 (Jan)	9.2 (Sep)
	MSJN02	7.4	4.9 (Apr)	12.7 (Sep)
	NSEX01	6	2.7 (Aug)	13.0 (Mar)
2006				
	CK200P	7.1	2.5 (Jun)	13.5 (Sep)
	JSUR01	7.4	2.7 (Jun)	15.0 (Sep)
	KSBP01	6.4	2.6 (Jun)	12.5 (Sep)
	KSSK02	6.4	2.7 (Jun)	12.0 (Sep)
	LSKQ06	7.3	3.5 (Jun)	12.0 (Aug)
	LSNT01	7.6	4.0 (Jun)	15.0 (Aug)
	LTBC43	5.9	2.0 (Dec)	14.3 (Sep)
	LTED04	5.5	2.5 (Dec)	10.5 (Sep)
	MSJN02	8.1	4.0 (Jun)	13.0 (Sep)
	NSEX01	7	3.5 (Dec)	13.5 (Aug)
	RT625NP	7.3	3.0 (Jun)	14.5 (Aug)
	RT625SP	7.5	2.7 (Jun)	15.0 (Aug)
2007				
	CK200P	7.3	4.8 (Jun)	9.1 (Nov)
	JSUR01	6.8	4.0 (Jun)	8.0 (Dec)
	KSBP01	7	4.2 (Jun)	9.0 (Sep)
	KSRU03	4.9	2.3 (Jun)	6.4 (Oct)
	KSSK02	7.6	5.8 (Jan)	11.0 (Oct)
	LSEP01	8.2	6.8 (Jan)	11.6 (Sep)
	LSKQ06	7.8	4.0 (May)	10.2 (Sep)
	LSNT01	8.3	5.0 (May)	12.6 (Sep)
	LSVV01	7.4	3.7 (Aug)	11.8 (Sep)
	LTBC43	6.8	1.7 (Feb)	11.7 (Oct)
	LTED04	7	1.7 (Feb)	15.0 (Oct)
	MSJN02	7.6	4.2 (Aug)	12.0 (Sep)
	NSEX01	6.8	3.0 (May)	14.5 (Oct)

Outfall stations
Ambient stations





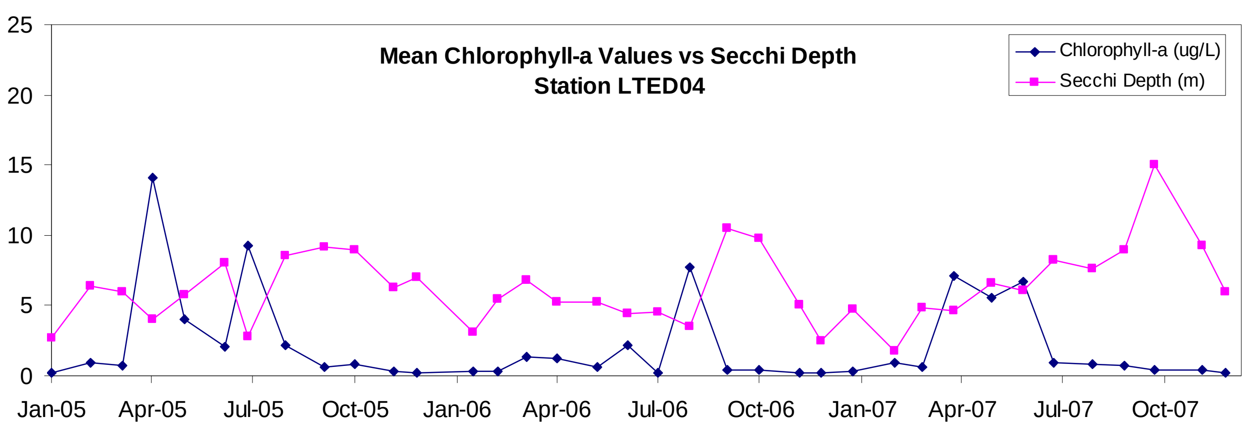


Figure 3-24. 2005-2007 Mean Values for Chlorophyll-a vs Secchi Depth Values for Stations CK200P, KSBP01, and LTED04.

Photosynthetically Active Radiation. Photosynthetically active radiation (PAR), also expressed as light intensity, is a measure of the amount of light available to macrophytes and phytoplankton for photosynthesis. Light penetration refers to the amount of sunlight that penetrates the water column and reaches various depths. Sunlight is absorbed and scattered by suspended particles, dissolved substances, and the water itself. Light penetration is monitored in order to determine if it is sufficient to support photosynthesis. As expected, the highest PAR levels occurred at or near the surface throughout the year, for all three years, at each station. The highest penetration of surface PAR occurs during winter when productivity is relatively low. Light penetration decreases during the spring and summer blooms. Even at the 1m depth, light penetration during phytoplankton blooms generally decreases to about 20% of available light. In Elliott Bay, light penetration at the surface can be as low as 9%, as was measured in August 2007.

By the 15 m depth, light penetration generally decreases to about 2% of the available surface light and less than 1% of light penetrates to 20 m and below. PAR measurements at discrete depths are located in Appendix A.

3.2.6 Nutrients

Nitrogen Compounds

Nitrogen is ubiquitous in the marine environment and occurs in many organic and inorganic chemical forms. Nitrogen compounds are frequently the limiting factor affecting phytoplankton growth in marine systems. The most abundant components of the marine nitrogen cycle affecting phytoplankton growth are nitrate (NO_3^-), nitrite (NO_2^-), and the ionic form of ammonia (NO_4^+). In the water column of most estuaries, nitrate + nitrite concentrations are frequently inversely correlated with chlorophyll-a concentrations in surface waters; especially when observed on a seasonal time scale. Conversely, patterns in ammonium concentrations are more volatile indicating rapid, year-round efficient uptake by nitrifying bacteria and phytoplankton. King County reports dissolved ammonia concentrations (ammonium ion that has been converted to ammonia), and the sum of nitrate and nitrite concentrations (nitrate+nitrite) due to the analytical methodology employed. Nitrite concentrations in the water column are naturally low compared to nitrate, so the nitrate + nitrite results can be considered almost entirely nitrate. All nutrient samples are filtered prior to analysis; therefore, the concentrations reported are for the dissolved fraction. The monitoring of nitrogen compounds allows King County to assess nutrient concentrations at wastewater and CSO treatment plant marine outfalls and to determine whether ammonia concentrations are at toxic concentrations to aquatic organisms in the Central Basin.

Ammonia

Offshore Waters. Of the nutrients measured by King County, ammonia is the only one with a published criterion for marine water quality as it can be toxic to marine plants and animals in high concentrations. In marine waters, ammonia can be found at elevated concentrations as a byproduct of sewage (both municipal and septic treatment systems), agricultural practices, and fertilization practices in urban areas. Elevated ammonia levels are also seen following large phytoplankton blooms as ammonia is produced during the decay process. Ecology's water quality standards for ammonia in marine waters with respect to aquatic organisms are based upon un-ionized ammonia and are less than 0.035 mg/L for long-term effects (chronic) and less than 0.233 mg/L for short-term effects (acute) (WAC, 173-201A, 2003). Ecology cites an EPA document for more specific criteria for total ammonia (which King County measures) based on temperature, salinity, and pH values. Assuming a temperature of 15 °C, a salinity of 30 PSS, and a pH of 8.0, the total ammonia chronic criterion is 1.6 mg/L (EPA, 1989).

Concentrations of ammonia ranged from less than the MDL (0.010 mg/L) in all three years to 0.25 mg/L in 2005, 0.19 mg/L in 2006, and 0.20 mg/L in 2007. As in previous years, the maximum concentration in 2005 was detected at station KSSK02 (West Point outfall) at 55 m. The maximum concentrations in 2006 and 2007 occurred at stations RT625NP (South Plant Outfall) and MSWH01 (Quartermaster Harbor), respectively. The mean concentration for all stations and depths was 0.02 mg/L for all three years. The highest concentrations of ammonia usually occur in the summer and fall months and the lowest concentrations occur in the winter months. Figures 3-25 and 3-26 show the vertical profiles for ammonia concentrations at selected ambient and outfall stations from 2005 to 2007. If any sample result was below the 0.01 mg/L detection limit, a value of 0.01 mg/L was assigned to that result in order to create the figures. The ammonia values in surface waters for the East Passage station (NSEX01) in 2007 (see Figure 3-25) are likely due to degradation of phytoplankton, as indicated by high chlorophyll values.

Ammonia concentrations from both outfall and ambient offshore stations generally increased with depth, illustrating that uptake is primarily from phytoplankton in the photic zone and lowered uptake and increased excretion by zooplankton is occurring below the photic zone. The highest concentration measured was more than six times lower than the criterion. The complete dataset of 2005-2007 offshore ammonia concentrations can be found in Appendix A.

Beach Waters. Ammonia concentrations at beach stations ranged from a minimum of less than MDL (0.010 mg/L) in all three years to 0.050 mg/L in 2005, 0.083 mg/L in 2006, and 0.164 mg/L in 2007. The mean concentrations were 0.019 mg/L, 0.020 mg/L, and 0.027 mg/L in 2005, 2006, and 2007, respectively. The highest concentrations generally occurred during warmer months (May – October), particularly during times when large amounts of decaying seaweed are typical along the shoreline (Figure 3-27). This was particularly evident in July of 2006 and 2007 when the highest average concentrations were measured. An abundance of the green seaweed *Ulva spp*. was observed along much of the shoreline in 2006 due in part to climate conditions—warm air temperatures in early spring and summer. Warmer than normal conditions began in April 2006 with exceptionally warm air temperatures occurring in July. July 2006 temperatures were almost four degrees higher than the long-term average which provided optimal growing conditions for seaweed. Although not as warm as in 2006, the first two weeks in July 2007 were warm, including one 98 degree day. The increase in ammonia concentrations throughout the summer in 2006 and 2007 at station KSQU01 shown in Figure 3-28 corresponds to an abundance of seaweed. An excess of *Ulva spp*. at this site during the summer was noted by residents living near Shilshole in both 2006 and 2007.

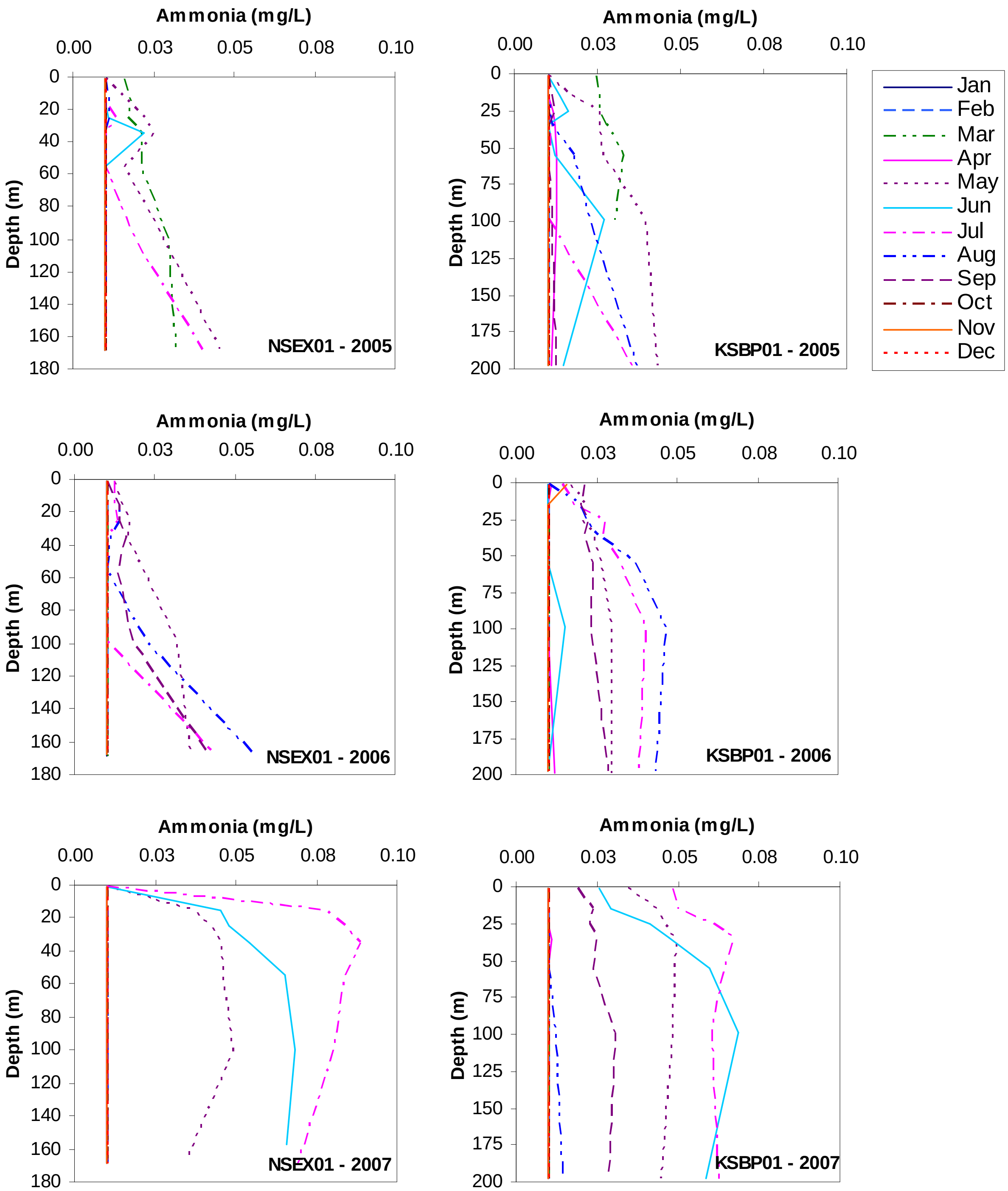


Figure 3-25. 2005-2007 Ammonia Profiles for Ambient Stations NSEX01 and KSBP01

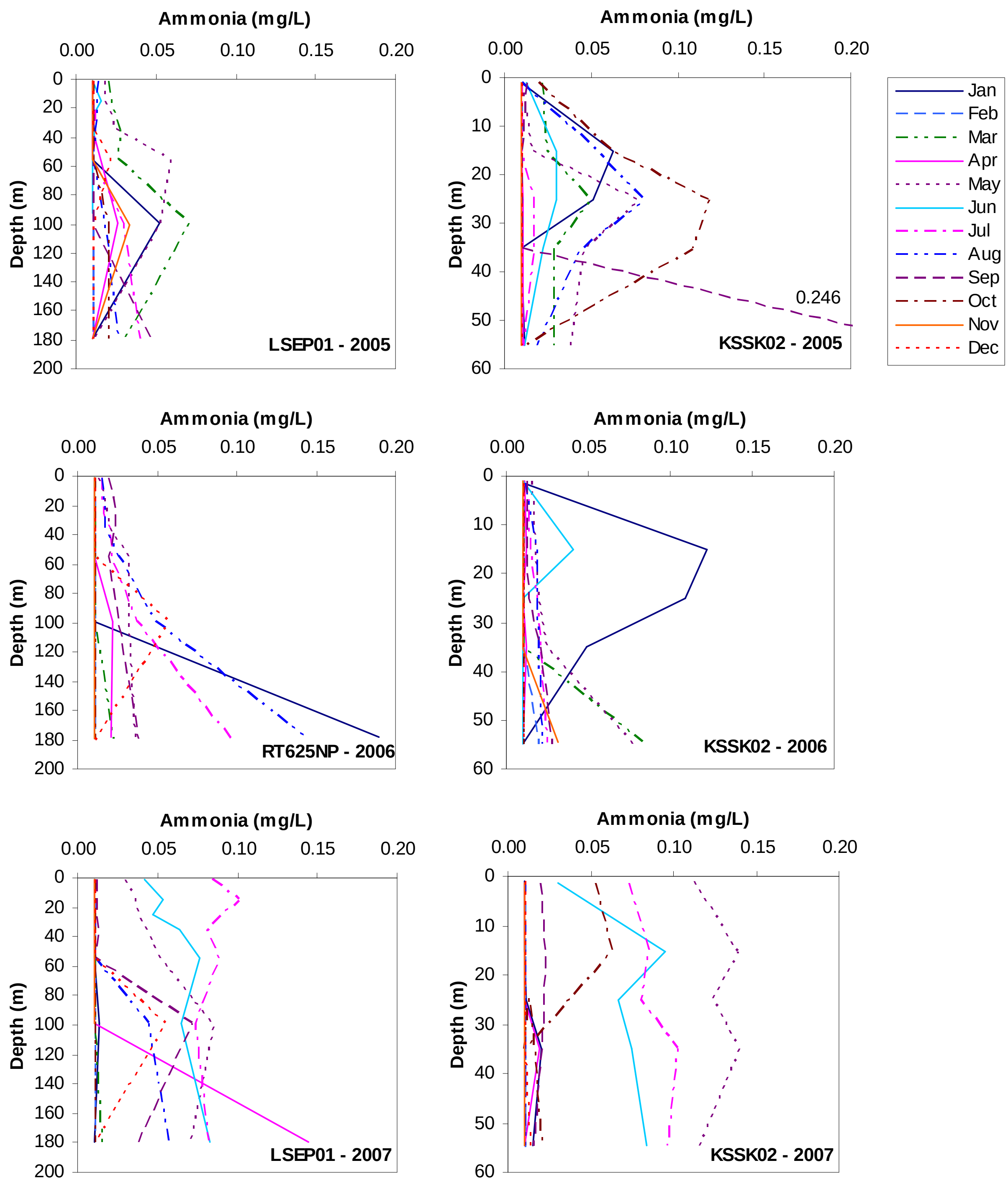


Figure 3-26. 2005-2007 Ammonia Profiles for Outfall Stations LSEP01 and KSSK02

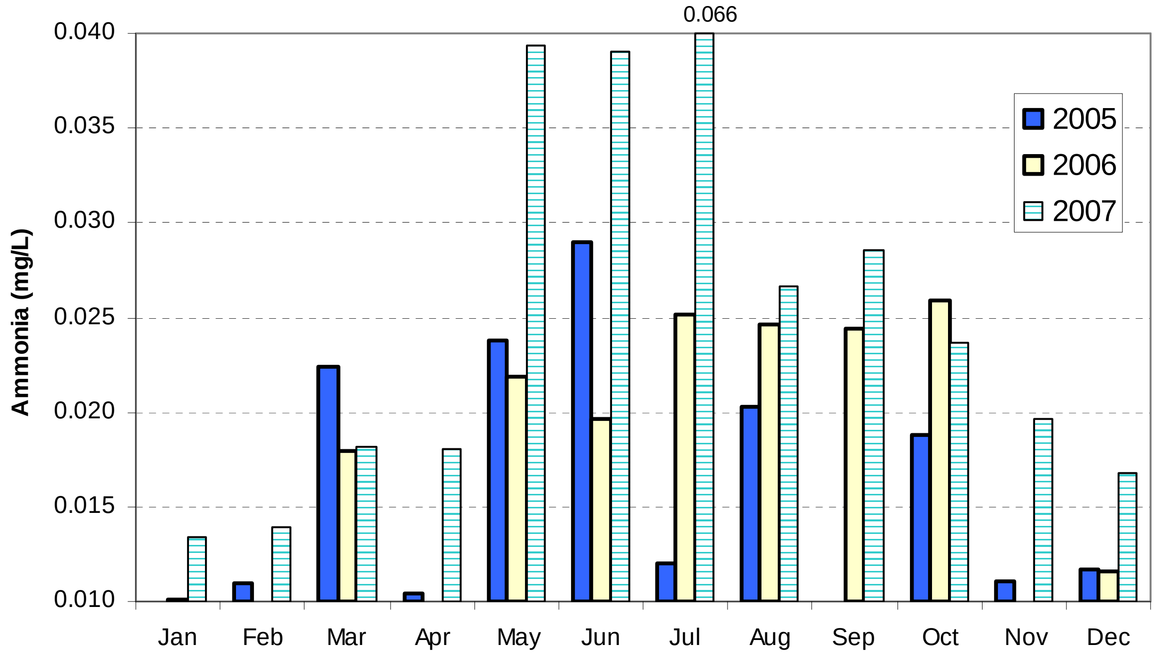


Figure 3-27. Average Monthly Ammonia Values for Beach Stations

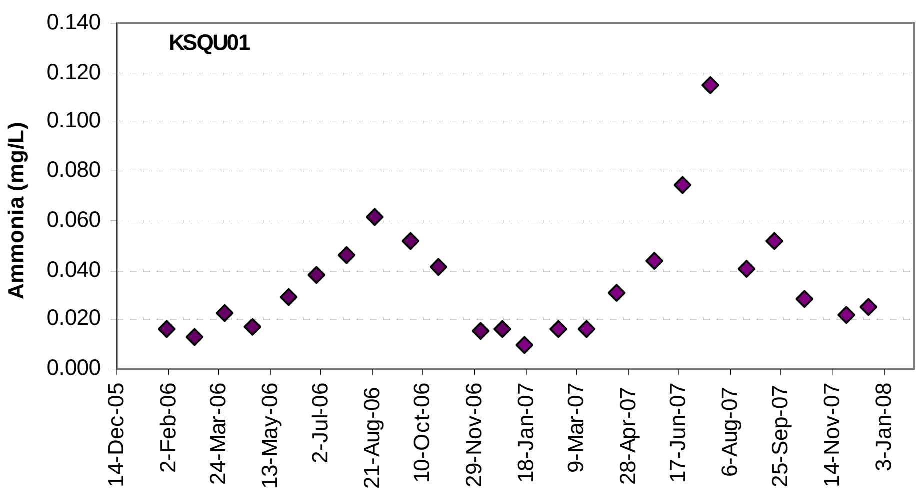


Figure 3-28. Ammonia Values at Station KSQU01 in 2006 & 2007

The ammonia concentrations at stations near the West Point and Carkeek TPs were similar to, if not lower, than concentrations at ambient stations. Values at the LSKS01 located in the vicinity of the Alki CSO TP outfall were higher than ambient stations, likely due to proximity to a storm drain along the shoreline which drains the hillside. A shoreline inspection in 2006 showed that this station is directly in front of a storm drain with a constant discharge.

Station MSJL01 in the vicinity of the Vashon Treatment Plant, along with station LSKS01, had the highest average ammonia concentrations in 2005. Gorsuch Creek is near station MSJL01 and has a considerable influence on water quality at this site. The highest concentrations in 2006 were measured at Normandy Park (MTLD03) and Shilshole (KSQU01). In 2007, the highest concentration (0.164 mg/L) was measured at Seahurst Park (MTEC01). This station was added to the sampling program in 2007 and was not sampled in either 2005 or 2006. Figure 3-29 shows ammonia values at all beach stations between 2005 and 2007. It should be noted that 11 new stations were sampled in 2007 that were not sampled in 2005 or 2006.

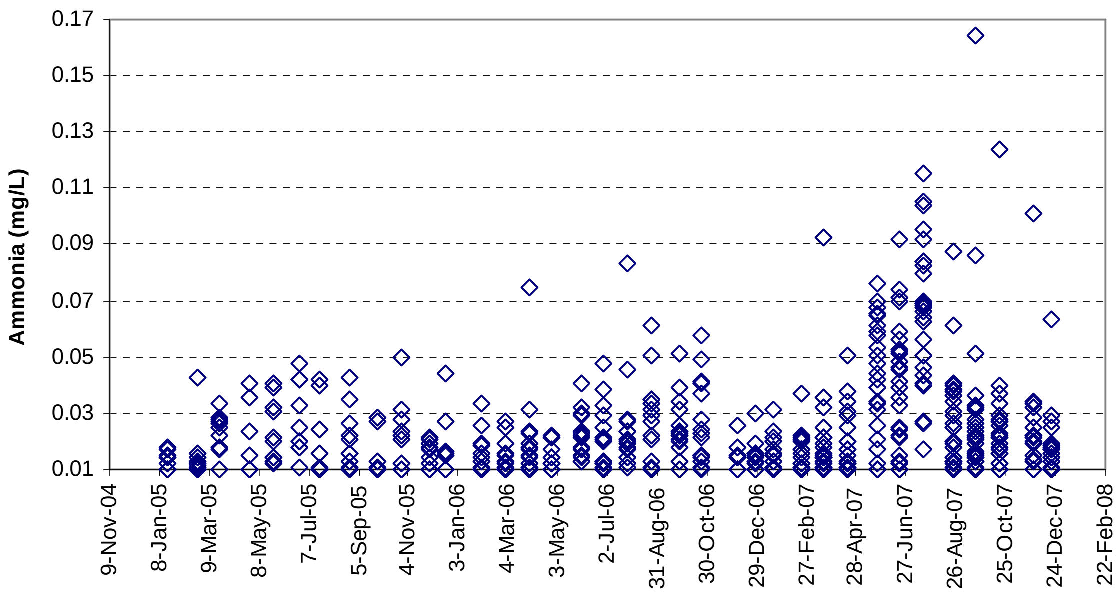


Figure 3-29. Ammonia Values at Beach Stations from 2005-2007

All measured ammonia concentrations at beach stations were significantly lower than the water quality criterion recommended by the EPA.

Nitrate + Nitrite

Offshore Waters. Nitrate+nitrite concentrations ranged from less than the MDL (0.02 mg/L) in all three years to 0.56 mg/L in 2005, 0.48 mg/L in 2006, and 0.46 mg/L in 2007. Surface concentrations of nitrate+nitrite were highest in late fall through early spring when nutrient uptake by phytoplankton is at a minimum and fluvial input was highest. Concentrations declined in the upper portion of the water column during the spring and summer months due to increased levels of nutrient uptake by phytoplankton. The mean concentrations for all stations and depths combined were 0.32 mg/L in 2005, 0.34 mg/L in 2006, and 0.33 mg/L in 2007. Figure 3-30 shows vertical profiles for nitrate+nitrite concentrations at stations KSSK02 and KSBP01 for 2005 to 2007. Concentrations generally increase with depth due to nitrate uptake in the photic

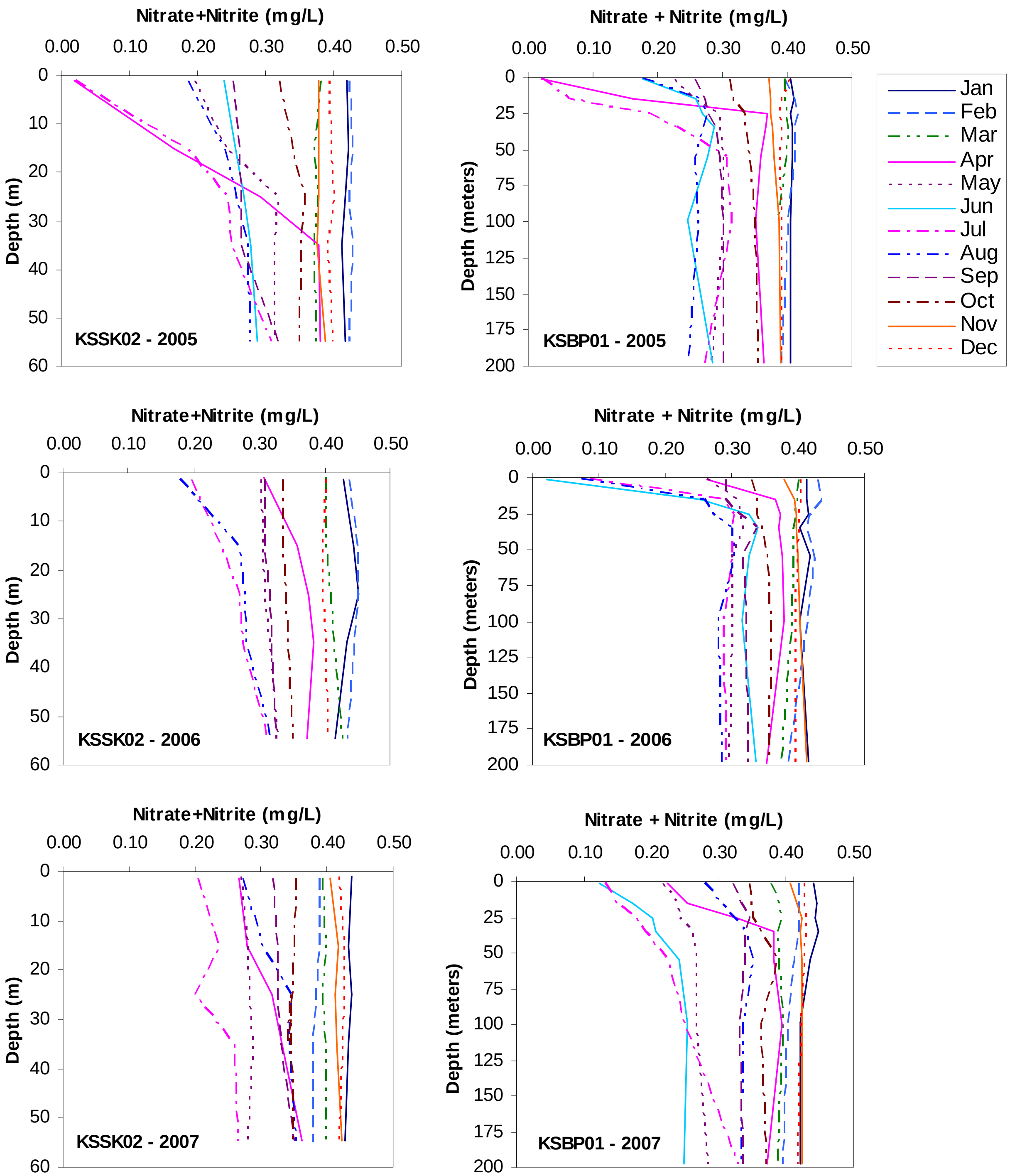


Figure 3-30. 2005-2007 Nitrate+Nitrite Profiles for Stations KSSK02 and KSBP01

zone by phytoplankton. The complete dataset of 2005-2007 offshore nitrate+nitrite concentrations can be found in Appendix A.

Beach Waters. Concentrations of nitrate+nitrite at beach stations (excluding the Piper's Creek station) ranged from less than the MDL (0.02mg/L) in all three years to 0.84 mg/L in 2005, 1.01 mg/L in 2006, and 0.87 mg/L in 2007. Mean concentrations for all beach stations combined were 0.25, 0.30, and 0.28 mg/L, respectively in 2005, 2006, and 2007. Figure 3-31 shows nitrate+nitrite concentrations at all beach stations sampled between 2005 and 2007. In 2005 and 2006, the highest concentrations were found at stations KSHZ03 and ITCARKEEKP, respectively. This is most likely due to the freshwater influence of nearby Piper's Creek. In 2007, the highest concentration was measured at the Dumas Bay station (NSJY01). Overall, the patterns were similar to those of the offshore stations; concentrations were highest in the winter and lowest in the summer. This seasonal variation at beach locations is typical of an ecosystem containing marine vegetation. Nitrate+nitrite concentrations are lower in the summer months when vegetation, including phytoplankton, seaweed, and kelp, take up nitrates for biological processes. Nitrate+nitrite was depleted to levels below the detection in April and July in 2005, June 2006, and at various times throughout the spring and summer in 2007. A notable exception was the site at Burton Acres in Quartermaster Harbor. Nitrate+nitrite was depleted below 0.02 mg/L from April to September, which was not seen at other stations nor for that length of time.

The Piper's Creek station (KTHA01) had much higher concentrations than the marine sites, with maximum concentrations between 1.59 and 3.09 mg/L from 2005 to 2007. Nitrate+nitrite concentrations and the seasonal pattern exhibited in Piper's Creek are typical of those in urban creeks and streams draining into Puget Sound (Figure 3-32).

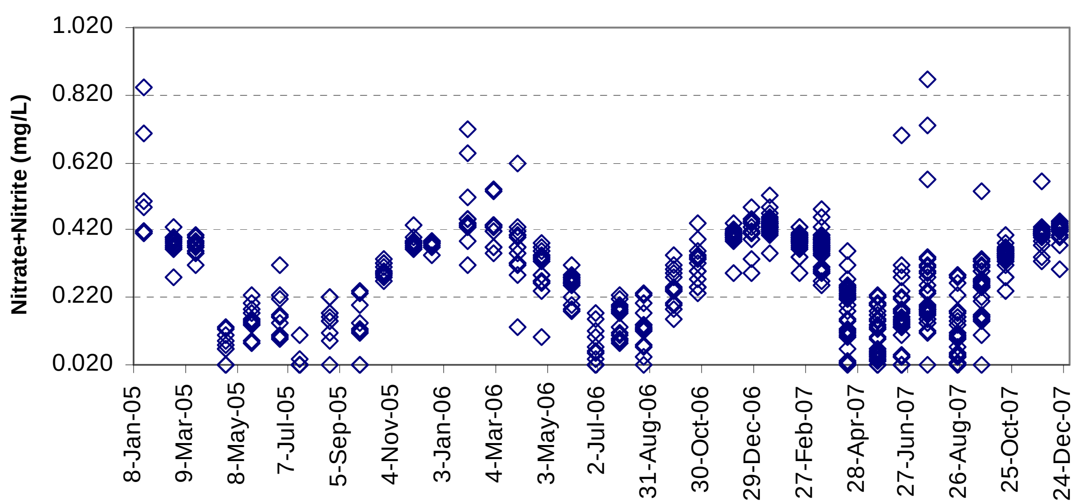


Figure 3-31. Nitrate+nitrite Values at Marine Beach Stations from 2005-2007

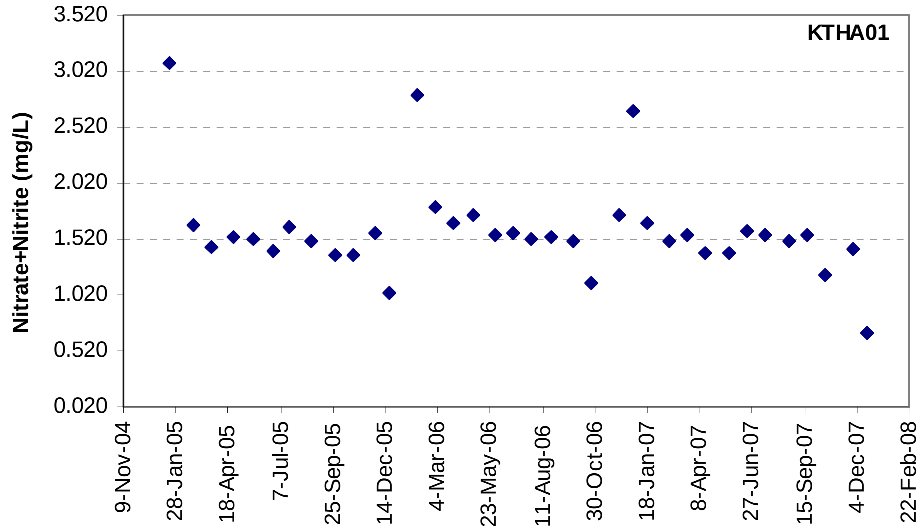


Figure 3-32. Nitrate+nitrite Values in Piper's Creek from 2005-2007

Total Phosphorous

Offshore Waters. Phosphorous occurs as dissolved inorganic, dissolved organic, and particulate phosphorous in seawater. Generally, particulate phosphorous is the most abundant of the three forms. There are several forms of inorganic phosphorous found in the marine environment, with the most abundant being orthophosphate. Total phosphorous, which includes all forms of inorganic and organic phosphorous, is measured by King County.

Phosphorous concentrations at all offshore stations (all discrete measurements combined) ranged from 0.026 to 0.650 mg/L in 2005, 0.029 to 0.110 mg/L in 2006, and 0.038 to 0.110 mg/L in 2007. Mean concentrations were 0.070 mg/L in 2005, 0.072 mg/L in 2006, and 0.076 mg/L in 2007. These results are comparable to previous years. A seasonal trend in phosphorous concentrations was observed; highest concentrations occurred in the winter and lowest concentrations occurred during summer in surface waters where photosynthesis was actively occurring. The complete dataset of 2005-2007 offshore phosphorous concentrations can be found in Appendix A.

Beach Waters. Total phosphorous at the beach stations ranged from 0.024 to 0.284 mg/L in 2005, 0.035 to 0.961 mg/L in 2006, and 0.026 to 0.514 mg/L in 2007. Mean concentrations were 0.083 mg/L in 2005 and 0.085 mg/L in 2006 as well as in 2007. Variability was greater at beach stations that at offshore stations due to differences in freshwater inputs (greater at beach stations due to proximity to streams and rivers). The complete dataset of 2005-2007 beach phosphorous concentrations can be found in Appendix A.

Silica

Offshore Waters. Silica concentrations at offshore stations ranged from less than MDL (<0.050) in both 2005 and 2006 to a maximum of 4.2 mg/L and 5.2 mg/L, respectively. Values ranged from 0.35 to 6.0 mg/L in 2007. Mean concentrations were 2.6 mg/L in 2005, 2.9 mg/L in 2006, and 3.1 mg/L in 2007.

The minimum concentrations seen in 2005 and 2006 were unusual as concentrations are rarely below the detection limit. These low values occurred at stations KSBP01 (Point Jefferson) and JSUR01 (Point Wells) in July of 2005 and at stations MSWH01 and NSAJ02 (Quartermaster Harbor) in June of 2006. In both years the <MDL values were measured during the second large phytoplankton bloom of the year. The first bloom of the year occurred in April of both 2005 and 2006, during which nitrate+nitrite levels were depleted to a level at which they could not be detected (<0.020 mg/L). Silica concentrations, however, ranged from 0.18 to 1.75 mg/L, indicating that the spring bloom was nitrogen limited. The phytoplankton blooms during July 2005 and June 2006 were so large that silica likely became the limiting growth factor, rather than nitrogen. Although sufficient nitrate+nitrite levels were available in the water column to sustain the bloom, silica was depleted before nitrogen could become limiting. Low silica values during the summer months are expected when diatoms that use silica for frustule growth are most abundant; however this was the first time that silica concentrations were below the MDL. Aside from the two unusual circumstances mentioned above, a seasonal trend in silica concentrations was observed. Concentrations tended to be lowest in the surface layer during the summer months and highest during the winter months when uptake by phytoplankton was low and freshwater inputs were relatively high. Figure 3-33 shows vertical profiles for silica concentrations at stations CK200P and KSBP01 for 2005 to 2007. The complete dataset of 2005-2007 offshore silica concentrations can be found in Appendix A.

Beach Waters. Maximum silica concentrations at beach stations were slightly higher than those at offshore station due to the closer proximity of beach stations to sources of silica, but the mean concentrations throughout the year were similar to offshore stations. Silica can enter the marine environment from erosion of natural rock carried in freshwater runoff. Beach silica data are only available for 2005, as measurements stopped after 2005. Values in 2005 ranged from 0.33 to 7.6 mg/L, with a mean concentration of 2.6 mg/L. The highest value was measured in January at station KSHZ03 located at the mouth of Piper’s Creek near Carkeek Park. This station had higher values throughout the year than other sites as has been seen in previous years. The complete dataset of 2005 beach silica concentrations can be found in Appendix A.

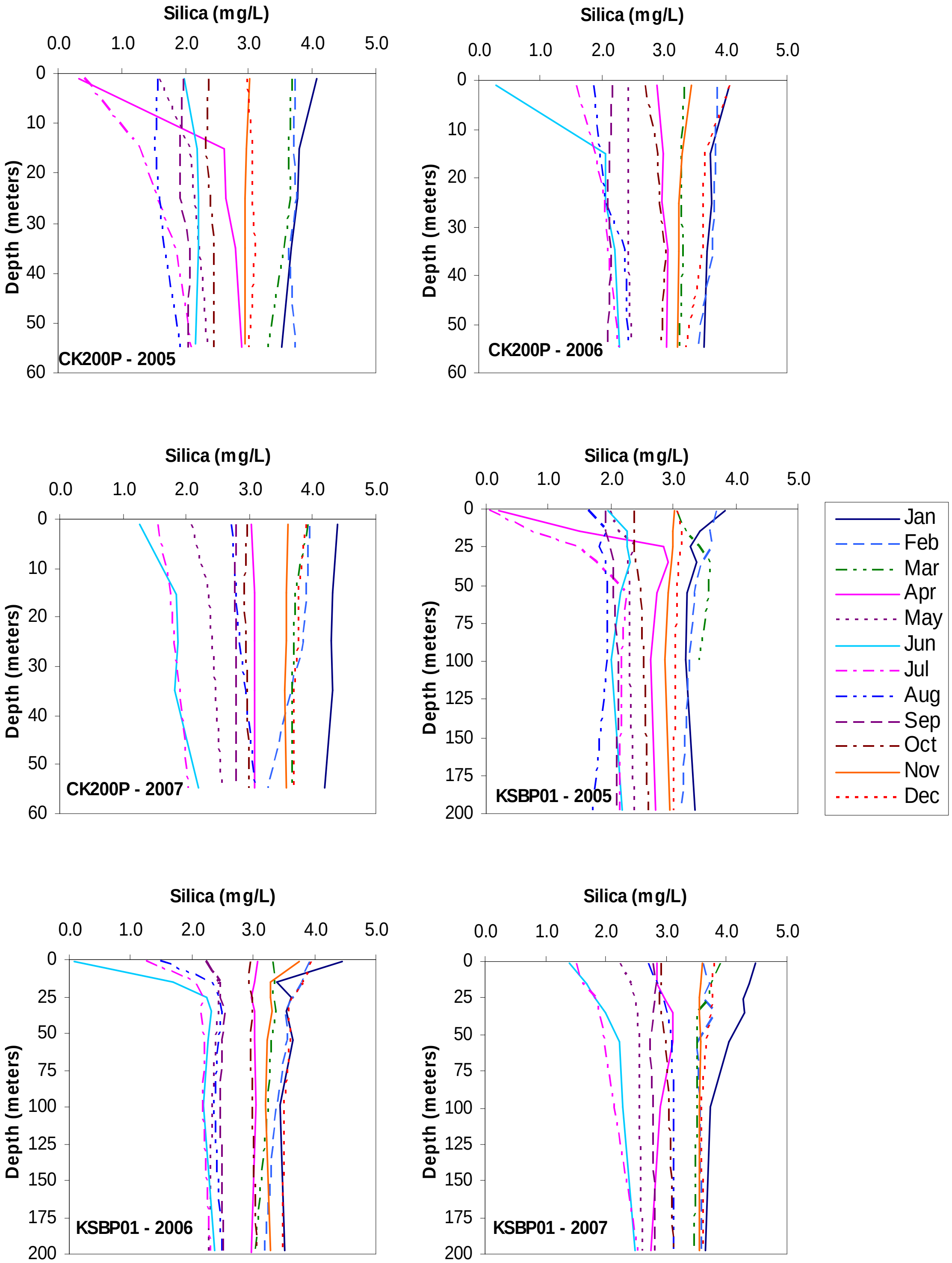


Figure 3-33. 2005-2007 Silica Profiles for Stations CK200P and KSBP01

3.2.7 Chlorophyll-*a* and Pheophytin

Phytoplankton are microscopic photosynthetic plants made up of two major groups, diatoms and dinoflagellates. Chlorophyll-*a*, the main pigment controlling photosynthesis, is the only pigment that is commonly present in all phytoplankton species, therefore, the amount of chlorophyll present can be used as an indicator of phytoplankton biomass. Chlorophyll can be degraded during natural senescence (die-off) of algal cells and also by grazing by herbivorous zooplankton. One of the degradation products of chlorophyll is pheophytin. Pheophytin is used as an indicator of physiological condition and also the amount of grazing on the phytoplankton.

In situ fluorescence measurements (an estimate of chlorophyll-*a*) were made at all offshore stations throughout the water column. In addition, discrete water samples were collected between 1 and 35 m and analyzed for chlorophyll-*a* and pheophytin in the laboratory. Discrete samples were not collected below 35 m as enough light does not penetrate to depths below 35 m to allow phytoplankton growth. Results from samples analyzed in the laboratory will be discussed as these tend to be more accurate quantitative measurements of chlorophyll abundance than those measured *in situ*, particularly when concentrations are high.

Between 2005 and 2007, chlorophyll-*a* values ranged from less than the detection limit to a high of 54.4 µg/L at Station MSWH01 (Quartermaster Harbor) in 2006. Other than the high value at the Quartermaster Harbor station, high values were measured in April of 2005 when large blooms (an accumulation of phytoplankton) were noted at most stations. In general for all three years, the spring bloom in April had the highest chlorophyll concentrations with the June bloom also having high concentrations. These high chlorophyll levels coincided with high oxygen levels in the surface layer produced through photosynthetic activity.

Figure 3-34 shows chlorophyll concentrations for the Point Jefferson and East Passage stations between 2005 and 2007. Figure 3-35 shows the occurrence of phytoplankton blooms between 2005 and 2007 as indicated by chlorophyll concentrations. It should be noted that samples are only collected monthly and it is possible that some phytoplankton blooms were missed. The length of phytoplankton blooms can vary from a day to a month, dependent on a variety of factors such as nutrient availability, the amount of tidal exchange, and weather conditions. Strong winds and a large difference between the high and low tides tend to make blooms dissipate rapidly. Even given the sampling limitations, the data indicate several spatial and temporal patterns. Phytoplankton blooms in the southern portion of the Central Basin (East Passage and Quartermaster Harbor) occurred both earlier and later in the year than at other stations. Blooms in East Passage and Quartermaster Harbor occurred as early as March and as late as October. The October 2006 bloom in Quartermaster Harbor was a large bloom, with a chlorophyll-*a* concentration of 43.5 ug/L at the inner harbor station. The spring bloom in 2005 was evident at all stations and all but one chlorophyll concentration was over 20 ug/L. Blooms in 2005 were captured throughout the spring and summer at most of the stations sampled, whereas no blooms were evident in early spring of 2006, with the exception of the East Passage and Quartermaster Harbor stations. It is likely the spring bloom occurred but was missed with monthly sampling.

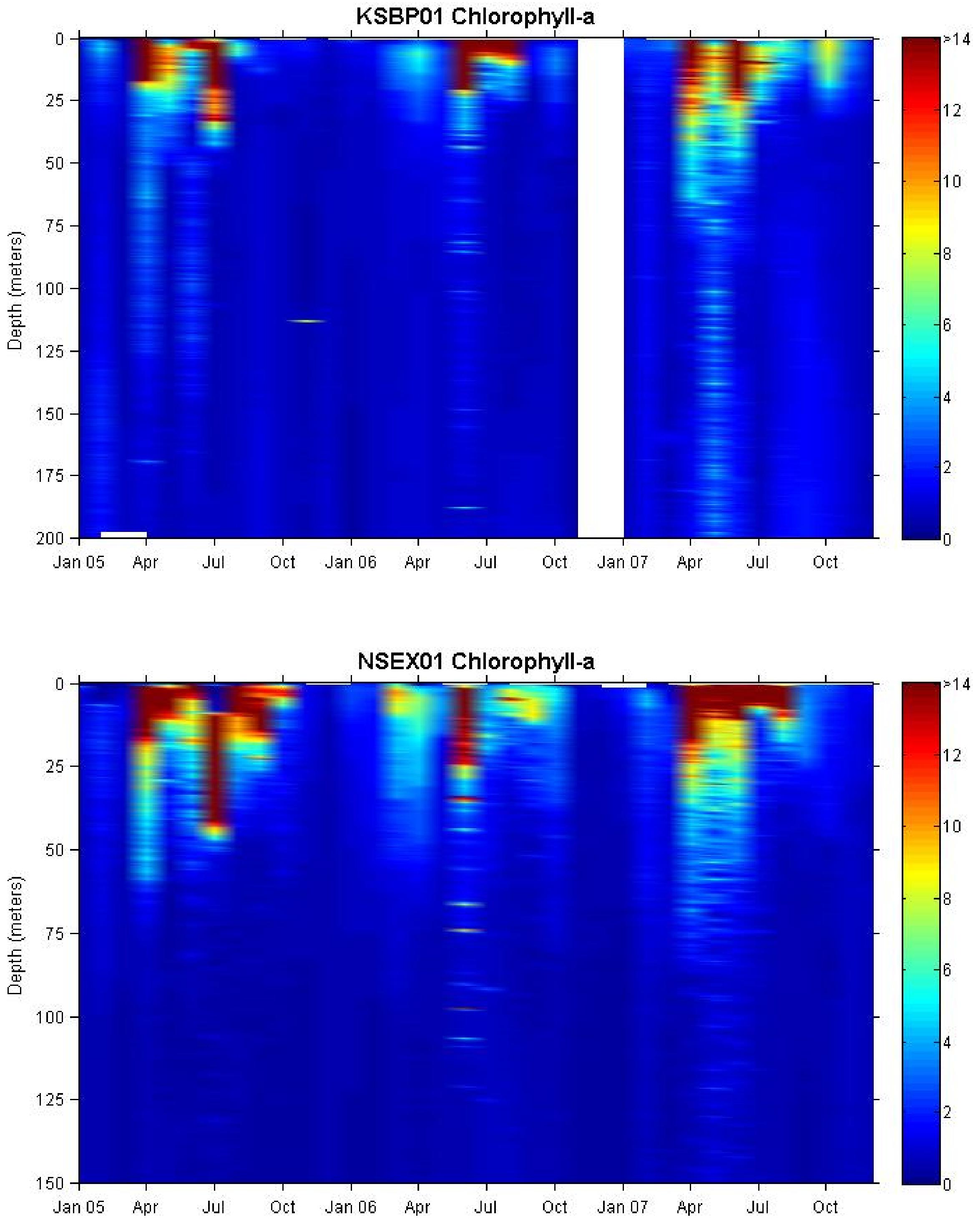


Figure 3-34. Chlorophyll-a Concentrations at Two Stations

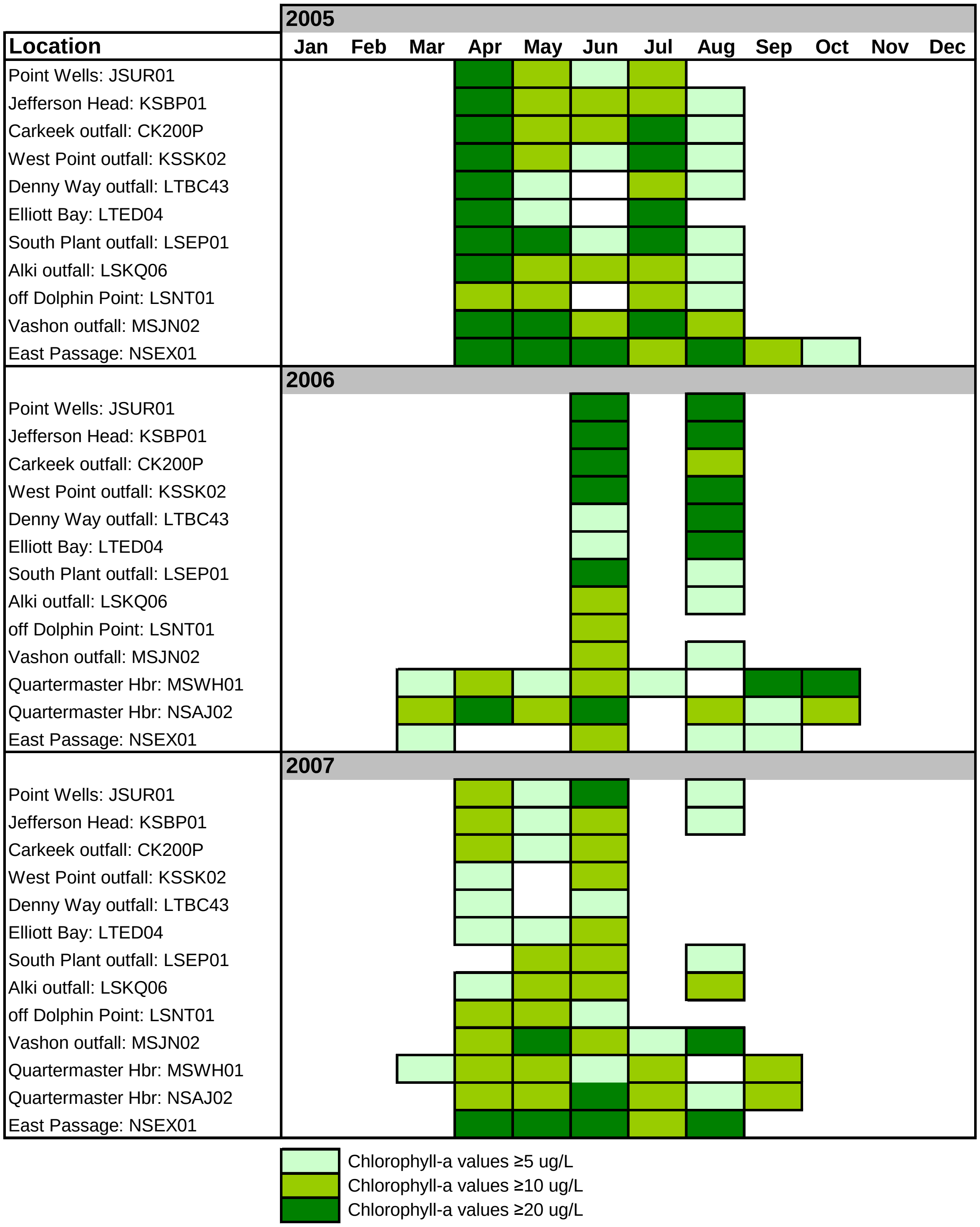


Figure 3-35. Phytoplankton Bloom Occurrence as Indicated by Chlorophyll-*a* Concentrations

Nitrogen, in the form of ammonia and nitrate+nitrite, was depleted in surface waters to levels below the detection limit due to phytoplankton uptake during the large blooms. When chlorophyll concentrations were equal to or above 20 µg/L, nitrate was depleted to undetectable levels approximately 35% of the time. Figure 3-36 shows the relationship between chlorophyll and nitrate+nitrite concentrations at the Point Wells station (JSUR01).

For all stations, the maximum chlorophyll concentration was not at the surface, but rather a few meters below the surface. The chlorophyll maximum was generally between four to six meters dependent upon the station and weather conditions. Several factors can influence the depth of where maximum chlorophyll concentrations are detected, including photoinhibition and water column stratification. Figure 3-37 shows the difference between the surface and bottom depth chlorophyll concentrations for the inner Quartermaster Harbor station MSWH01.

Pheophytin concentrations mirrored the seasonal chlorophyll concentrations, with higher amounts of pheophytin during phytoplankton blooms. Figure 3-38 shows pheophytin and corresponding chlorophyll-a concentrations.

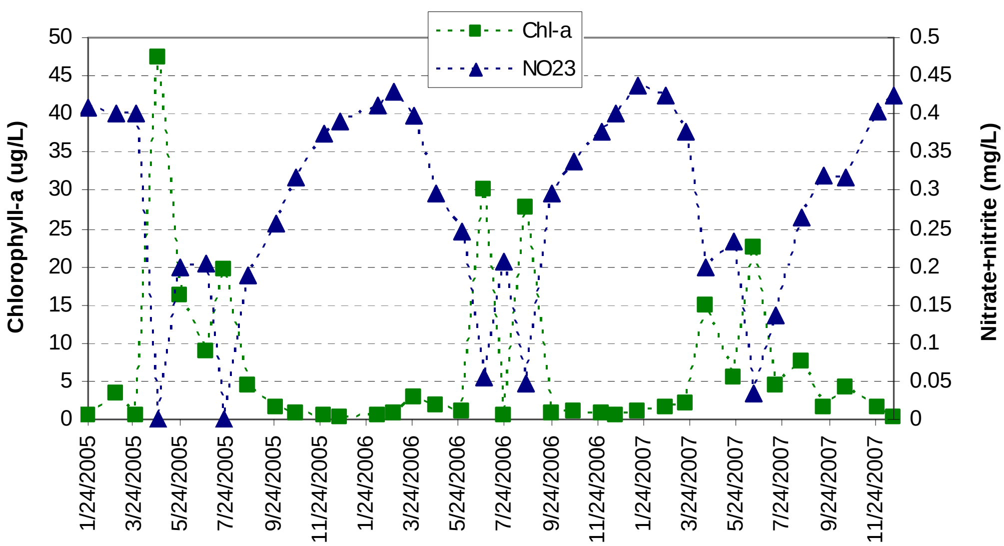


Figure 3-36. Chlorophyll-a and Nitrate+nitrite Concentrations at 1m for Station JSUR01

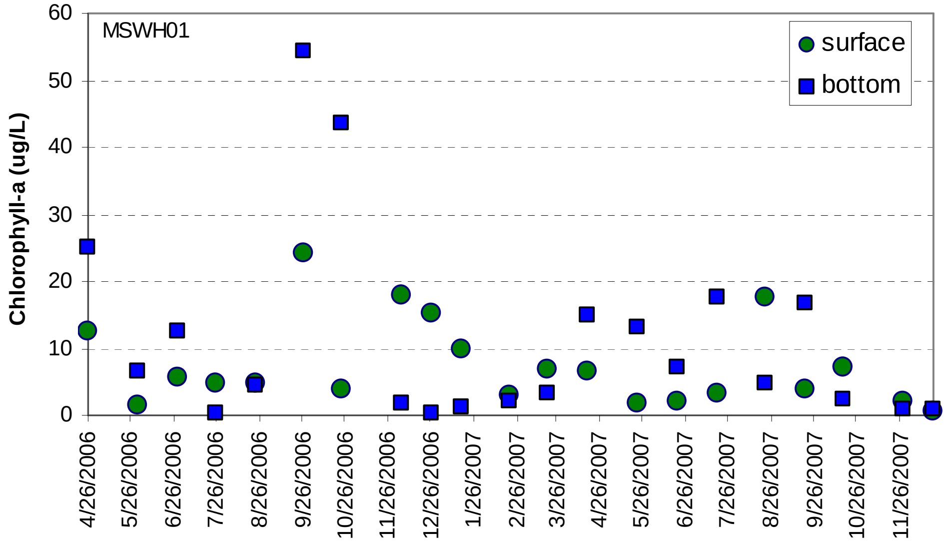


Figure 3-37. Chlorophyll-a Concentrations at Two Depths for Station MSWH01

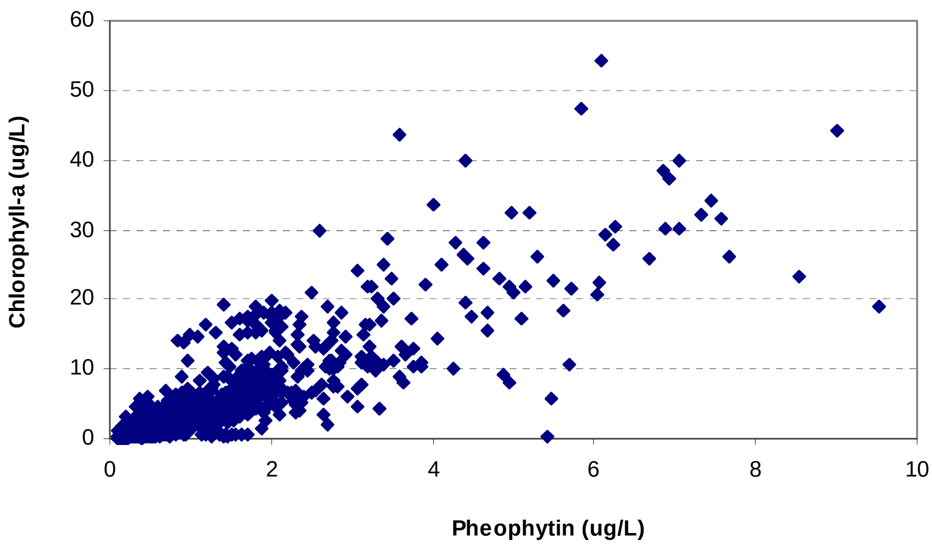


Figure 3-38. Relationship Between Pheophytin and Chlorophyll for Offshore Stations Between 2005 and 2007